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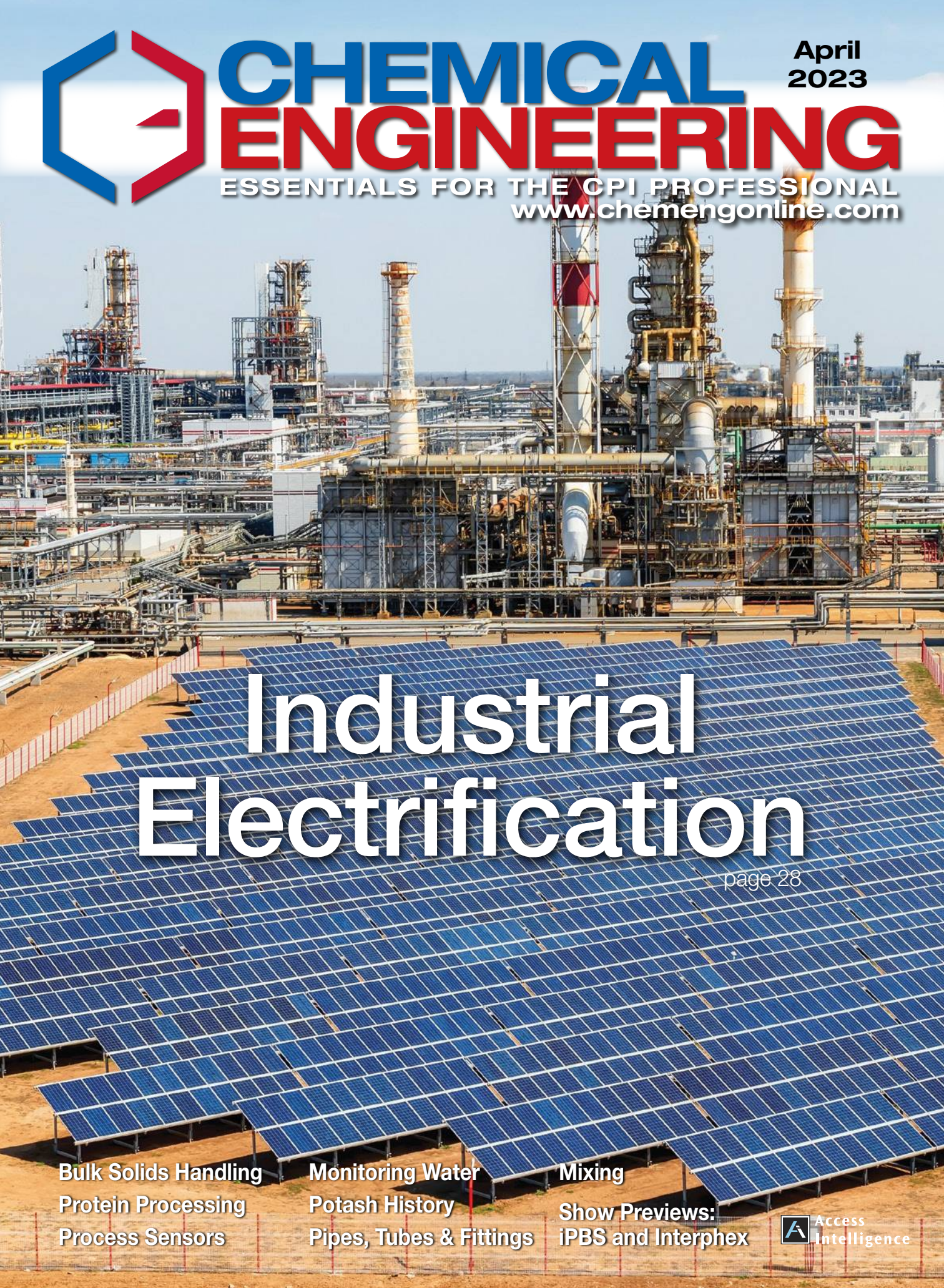

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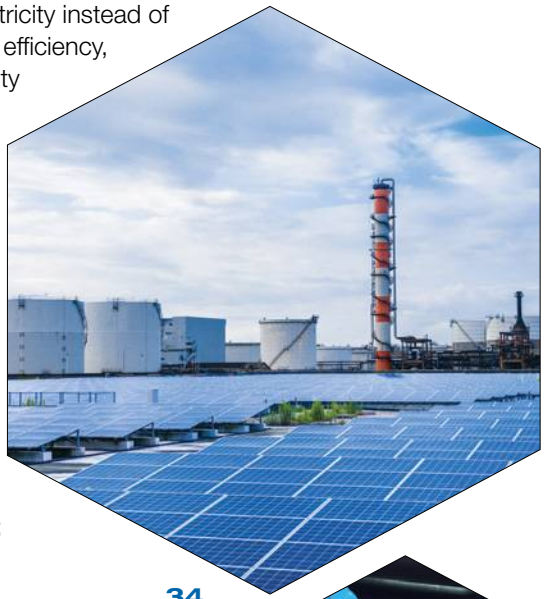

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CHEMICAL ENGINEERING
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EDITORS

DOROTHY LOZOWSKI
Editorial Director
dlozowski@chemengonline.com

GERALD ONDREY (FRANKFURT)
Senior Editor
gondrey@chemengonline.com

SCOTT JENKINS
Senior Editor
sjenkins@chemengonline.com

MARY PAGE BAILEY
Senior Associate Editor
mbailey@chemengonline.com

GROUP PUBLISHER

MATTHEW GRANT
Vice President and Group Publisher,
Energy & Engineering Group
mattg@powermag.com

AUDIENCE DEVELOPMENT

JENNIFER McPHAIL
Senior Marketing Manager
jmcphail@accessintel.com

GEORGE SEVERINE
Fulfillment Manager
gseverine@accessintel.com

DANIELLE ZABORSKI
List Sales: Merit Direct, (914) 368-1090
dzaborski@meritdirect.com

ART & DESIGN

TARA BEKMAN
Graphic Designer
tzaino@accessintel.com

PRODUCTION

GEORGE SEVERINE
Production Manager
gseverine@accessintel.com

INFORMATION SERVICES

CHARLES SANDS
Director of Digital Development
csands@accessintel.com

CONTRIBUTING EDITORS

SUZANNE A. SHELLEY
sshelley@chemengonline.com

PAUL S. GRAD (AUSTRALIA)
pgrad@chemengonline.com

TETSUO SATOH (JAPAN)
tsatoh@chemengonline.com

JOY LEPREE (NEW JERSEY)
jlepree@chemengonline.com

EDITORIAL ADVISORY BOARD

JOHN CARSON
Jenike & Johanson, Inc.

DAVID DICKEY
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HEADQUARTERS

40 Wall Street, 16th floor, New York, NY 10005, U.S.
Tel: 212-621-4900
Fax: 212-621-4694

EUROPEAN EDITORIAL OFFICES

Zeilweg 44, D-60439 Frankfurt am Main, Germany
Tel: 49-69-9573-8296
Fax: 49-69-5700-2484

CIRCULATION REQUESTS:

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Rockville, MD 20850-3240
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Editor's Page

Energizing the CPI

The first issue of this publication in September of 1902, then titled *Electrochemical Industry*, contained this statement from professor C.F. Burgess: "Chemical manufacturing was a number of years ago considered best developed when the processes were so simple that no power was necessary to assist in the chemical reactions, but this condition has changed and the chemical industries are now pre-eminently power-using industries."

The chemical process industries (CPI) have grown tremendously since that time, and according to the International Energy Agency (www.iea.org), the chemical sector is now the largest industrial energy consumer and the third largest industrial producer of CO_2 emissions.

While energy efficiency has long been a focus of the CPI, the current "energy transition," driven by sustainability and decarbonization goals, is in turn, driving the CPI to rethink energy sourcing and usage.

Industrial electrification

In response to the changing energy landscape, industrial manufacturers are investigating process electrification, which would allow renewable energy sources to be used in place of fossil fuels. This is becoming more feasible as the cost of wind and solar energy decreases. Options for industrial electrification, such as using electric motors in place of steam or gas turbines, electric heaters instead of fuel-fired ones, and heat-pumps, are discussed in detail in our two-part Cover Story on pages 28–38 of this issue.

Nuclear fission is another potential source of energy for industrial settings that is gaining attention with advances in small modular reactors (SMRs). SMRs are, as their name implies, small (generating up to 300 MW(e) per unit) and modular (can be factory assembled and brought to a location for installation). There are numerous SMR designs in development. Last month, the Nuclear Energy Agency (NEA; www.oecd-nea.org) introduced a publication that tracks the progress of 21 SMR designs toward commercialization. This "SMR Dashboard" can be found on NEA's website.

Also last month, Dow (www.dow.com) and X-Energy Reactor Co. LLC (X-energy; www.x-energy.com) announced a joint-development agreement to develop a four-unit Xe-100 facility at one of Dow's U.S. Gulf Coast sites. Xe-100 is X-energy's small modular nuclear high-temperature gas-cooled reactor (HTGR). This will be the first deployment of a grid-scale advanced nuclear reactor for an industrial site in North America.

Electrochemistry

Another pathway toward electrification in the CPI is development of electrochemical processes. While not new (recall that our first issue in 1902 was titled *Electrochemical Industry*), the emphasis on decarbonization is fueling strong interest in electrochemistry, including and beyond the much-discussed electrolytic route to hydrogen production.

Two examples of groups working in this area are: a recently formed, multidisciplinary collaboration between U.S. universities and national laboratories called DC-MUSE, which stands for Decarbonizing Chemical Manufacturing Using Sustainable Electrification (www.dc-muse.org); and the e-Refinery at TU-Delft in the Netherlands (www.tudelft.nl/e-refinery). Information about their programs can be found on their websites. And for further reading on electrochemistry, see "Electrochemistry Spreads its Wings," *Chem. Eng.*, pp. 12–16, Sept. 2021. ■

Dorothy Lozowski, Editorial Director

Electrolysis of seawater — without pre-treatment

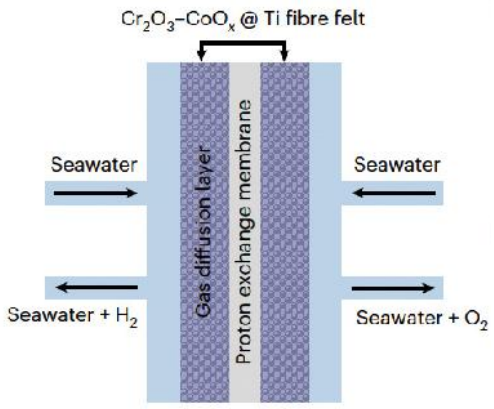
Current electrolyzers for producing hydrogen use purified water as feedstock, but in the future, this could exacerbate freshwater shortages in some areas. Seawater is highly abundant, but the ions it contains undergo electrode side reactions, and cause corrosion in proton-exchange membrane (PEM) electrolyzers. Now, an international research team has reported the direct electrolysis of real seawater into hydrogen and oxygen with nearly 100% efficiency in a commercial electrolyzer.

The electrolysis depends on a specially designed catalyst, with a Lewis acid layer (for example, Cr_2O_3) on transition-metal-oxide catalysts, such as cobalt oxide, to dynamically split water molecules and capture hydroxyl anions. Such *in-situ*-generated local alkalinity facilitates the kinetics of both electrode reactions and avoids chloride attack and precipitate formation on the electrodes, according to the researchers' report in a recent issue of *Nature Energy*.

"Our work provides a solution to directly utilize seawater without pre-treatment systems and alkali addition, which shows similar performance as that of an existing metal-based mature pure water electrolyzer," says Yao Zheng, associate professor at the University of Adelaide (www.adelaide.edu.au) and co-author of the study. "The performance of a commercial electrolyzer with our catalysts running in seawater is close to the performance of platinum/iridium catalysts running in a feedstock of highly purified deionized water."

The team is working on scaling up the system by using a larger electrolyzer so that it can be used in commercial processes, such as hydrogen generation for fuel cells and ammonia synthesis.

University of Adelaide



Quinones power this flow battery

A new flow-battery design is based on quinones — a plentiful material historically derived from coal tar and used in dyestuff manufacturing — rather than traditional battery electrolytes. "Our feedstocks use no critical materials like lithium, cobalt or nickel, and no fluorinated electrolytes, making them much cheaper than other battery materials," says Eugene Beh, CEO of Quino Energy (San Leandro, Calif.; www.quinoenergy.com). Quino's technology uses the flow-battery system as the production reactor to convert dyestuff raw materials into specialized quinones that come dissolved in water and are used as is as the battery's electrolyte, all with zero chemical waste. Quinones' high water solubility and chemical stability make them particularly good candidates for flow-battery reactants in mid-duration energy-storage applications.

The key to the quinone battery's performance is consideration of quinone decomposition. Collaborators at Harvard University discovered that the quinones decompose via a chemical, rather than an electrochemical, process, and that the decomposed material can be easily restored back to the original reactants. This periodic restoration process involves a mild oxidation, wherein air is bubbled through the battery electrolyte, or a "deep discharge" where the battery's capacity is fully exhausted to an extremely low state of charge. The quinone battery's resilience in deep-discharge situations, as well as the ability to restore the electrolyte material, both enable a longer lifespan than lithium-ion batteries.

Quino Energy has demonstrated a quinone flow battery at the pilot scale, says Beh, with the intention to integrate the pilot system into an onsite microgrid at their facility in San Leandro, Calif. in the second half of the year. To further develop the technology, the U.S. Department of Energy (DOE) awarded funding for external testing and validation of a prototype system at a national laboratory site. According to Beh, the company plans to have a significantly larger system (400-kWh capacity) available in the first half of 2024.

Edited by:
Gerald Ondrey

PARA-XYLENE FROM CO_2

Last month, a Japanese consortium announced the successful production and purification of *p*-xylene produced from CO_2 at pilot scale. The University of Toyama (www.u-toyama.ac.jp), Chiyoda Corp. (www.chiyodacorp.com) and HighChem Co., Ltd. (www.highchem.co.jp) have been collaborating on producing *p*-xylene from CO_2 as part of the research project, Development of Technologies for Carbon Recycling and Next-Generation Thermal Power Generation, under a program of the New Energy and Industrial Technology Development Organization (NEDO; Kawasaki; www.nedo.go.jp). The full project also includes participants from Nippon Steel Engineering Co., Nippon Steel Corp. and Mitsubishi Corp.

Since March 2022, Chiyoda's pilot plant, in Koyasu Research Park, has used HighChem's industrial catalyst, which is based on achievements of research at the University of Toyama, to produce *p*-xylene compounds utilizing CO_2 as feedstock. The *p*-xylene is purified in external facilities using conventional methods. This achievement is a next step towards commercializing the technology.

As with conventional *p*-xylene, the *p*-xylene produced from CO_2 is applicable to many types of resins and relevant chemicals via purified terephthalic acid (PTA). This new route to *p*-xylene (and PTA) has the potential to enable carbon recycling and thus, can reduce CO_2 emissions.

CURING SILICONES

Researchers at the Technical University of Denmark (DTU; Lyngby; www.dtu.dk) have patented a new method for curing silicones without using tin or other metal catalysts. Currently, the standard ways to cure silicones are through condensation reactions using a tin catalyst or through hydrosilylation using platinum catalysts. DTU's method allows fast and metal-catalyst-free curing

(Continues on p. 6)

using commercially available reagents — polysilazanes, carbinol silicones and silanol-terminated silicones — under ambient conditions.

Coatings and elastomers prepared by this methodology show the same characteristics as the corresponding silicone coatings and elastomers prepared by classical methods, even though the curing methodology is very different. Specific organic catalysts can be added to control the curing rate, permit coating and fast drying processes, and control cure kinetics. For all the mentioned systems, this technique will enable the removal of tin and platinum catalysts from current products. The patented method, which is available for license, is described in a recent article in *Macromolecular Materials and Engineering*.

EATING GRASS?

Dutch companies Schouten Europe B.V. (Giessen; www.schoutenfood.com) and Grassa B.V. (Venlo; www.grassa.nl) started a collaboration to develop meat substitutes using protein from grass as an alternative to soy protein. "Grass protein has massive potential," says Rieks Smook, director of Grassa. "Grass yields 2.5 times as much protein per hectare as soy. Grass supplies are readily available. Grass protein is a high-quality, local and scalable alternative to soy. When compared to other protein sources, it provides a huge reduction in the carbon footprint."

Grassa produces grass protein in its demonstration factory in Afferden. This protein is currently being used to co-develop products in pet food, aqua feed and compound feed for pigs and chickens. In addition, Grassa has tested and developed technologies to extract protein from grass that is suitable for human applications.

FUNGUS-BASED FOOD

Last month, the University of Borås (Sweden; www.hb.se) announced another milestone in its more than 20 years of research on fungi — a company will now use the findings to produce a completely new

(Continues on p. 8)

A new milestone for durable fuel-cell membranes

For the first time, a hydrocarbon-based membrane has passed the performance and durability testing standards set by the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov) for heavy-duty fuel-cell applications. Typically, membranes in fuel cells are made of perfluorinated materials like perfluorosulfonic acids (PFSAs), but such materials have several drawbacks, including significant environmental concerns and high costs for end-of-life precious-metal recovery. Pemion proton-exchange materials, developed by Ionomr Innovations Inc. (Vancouver, B.C., Canada and Rochester, N.Y.; www.ionomr.com), include no perfluorinated compounds, and create membranes that are said to be significantly more durable than previous hydrocarbon-based attempts.

"Pemion is a composite membrane. The polyarylene polymer is reinforced with hydrophobic materials that enable the dimensional stability required for system integration, while maintaining high through-plane conductance," explains Ben Britton, Ionomr's chief strategy officer. "The Pemion ion-exchange polymer benefits from a novel synthetic protocol that allows for extreme consistency of properties, including the same degree of functionality every time, eliminating concerns about batch-to-batch reproducibility often seen in other materials, perfluorinated or not," he adds. Furthermore, unlike PFSA materials, Pemion polymers are thermochemically stable up to 180°C, enabling a development platform for other fuel-cell components to reach industry operating targets of 120°C.

Pemion membranes underwent combined chemical and mechanical stability accelerated stress tests designed for fuel-cell membranes, as well as the DOE relative-humidity (RH) cycling mechanical-durability protocol. The tests, which were run for over 40,000 cycles with electrochemical assessments every 24 h, demonstrated stability of the membrane in various membrane electrode assembly (MEA) configurations. "Critically, MEAs containing Pemion membranes exhibited minimal thinning, minimal decreases in open-circuit voltage throughout the lifetime of the test and exceptionally low gas crossover, which increases cell efficiency and lifetime," says Britton. Beyond fuel cells, Ionomr sees applicability for the Pemion polymer membrane in electrochemical hydrogen compressors, sensors and humidifiers, as well as utility of the polymer itself in battery technologies.

Converting waste polyolefins to isoalkanes

Chemical recycling of waste polyolefins is difficult to achieve economically partly because of the stability of carbon-carbon bonds in the plastics. In a new approach, researchers at Pacific Northwest National Laboratory (PNNL; Richland, Wash.; www.pnnl.gov) and the Technical University of Munich (www.tum.de) have taken a step toward lowering the energy required to cleave the C-C bonds and directing the production of fuel products. To do this, they created a highly ionic reaction environment and combined the polymer-cracking reaction with a subsequent alkylation reaction in the same vessel. Using this process, the team was able to produce gasoline-like C6–C10 isoalkanes from polypropylene (PP) and low-density polyethylene (LDPE) waste.

Publishing in a recent issue of the journal *Science*, the research team reported an aluminum-chloride-based ionic-liquid medium that promotes the breakdown of the plastics. Specifically, the ionic medium "increases the polymer reactivity and lowers the energy of ionic transition states," the researchers say.

The C-C bond cleavage is followed by a targeted alkylation to form high-quality liquid alkanes using catalysts developed for petroleum refining.

PNNL chemist and study co-author Oliver Gutierrez explains that cracking and bond breakage can lead to uncontrolled bond formation, which can be a problem in other approaches. "The secret formula here is that when you break a bond in our system, you immediately make another one in a targeted way that gives you the end product you want," he says. And combining the endothermic cleavage of the polymer C–C bonds with exothermic alkylation reactions of the cracking products enables full conversion of LDPE and PP to liquid isoalkanes at temperatures below 100°C. The alkylate product forms a separate phase that is easily separated from the reactant catalyst mixture, the researchers say.

In their study, the researchers note the process works for LDPE and PP, but high-density polyethylene (HPDE) would require a pretreatment to allow the catalyst access to the bonds it needs to break.

meat alternative, called Millow. Millow is a mixture of mycelium (fungus) and oats, and is also the name of the company planning to launch first products on the Nordic market next year.

The fungus grows on material such as grain or vegetables, but also on various residual material, and forms a fungal biomass. From that biomass the researchers can then make new products, in this case a healthy and planet-friendly alternative to meat. The product is said to have an advanced texture without any food binders, thanks to the natural properties of the mushrooms.

For more on alternative proteins, see pp. 12–16.

REDUCING CO_2

The Lapwing Estate Ltd. (Doncaster, U.K.; www. www.thelapwingestate.co.uk) has commissioned Bilfinger SE (Mannheim, Germany; www.bilfinger.com) to build a pilot plant for its "reverse-coal approach" (www.reversecoal.co.uk) to reduce CO_2 in the atmosphere. Bilfinger will be responsible for the technical planning, procurement and installation of the plant. Completion of the high-temperature pyrolysis plant in the English county of Nottinghamshire is planned for late 2023.

The pilot plant is part of the "reverse coal process" developed by The Lapwing Estate. The aim of this process is to convert CO_2 emissions back into solid carbon, while producing food with measurable positive environmental and social impact. To do this, peatlands are first rewetted and planted with willow coppice, allowing the peat to slowly rebuild, abating CO_2 emissions from the land, and capturing atmospheric CO_2 through photosynthesis. Biomass is then rotationally harvested, chipped and fed into a high-temperature pyrolysis plant, which produces renewable heat, electricity and biochar. When the biochar is buried underground (reverse coal), the raised land remains productive, and the heat and electricity are supplied to controlled environment (indoor) agriculture (CEA), which replaces land transferred to

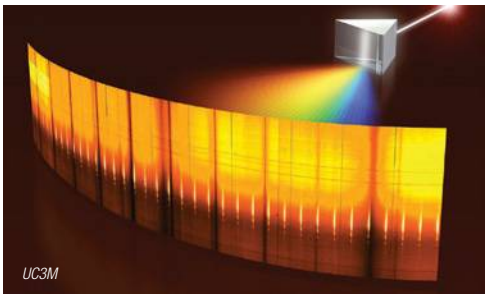
(Continues on p. 9)

Patented technology captures real-time 'hyperspectral' images

The Universidad Carlos III de Madrid (UC3M; Spain; www.uc3m.es) has patented a new system for capturing hyperspectral images — those capable of collecting information across a broad frequency range of the electromagnetic spectrum (near-infrared, mid-infrared and terahertz). The system can operate in real time and provides a higher resolution than any other existing technology, according to UC3M. The development could mean a breakthrough for chemical analysis in scientific and industrial applications.

Developed and patented by UC3M's Sensors and Instrumentation Techniques group, this system is made up of a light source that transforms a normal camera into what is known as a hyperspectral camera, which can measure the absorption spectra of a sample and not only identify the components, but also determine concentrations, temperature and pressure. To do this, an advanced analytical technique, known as dual-comb spectroscopy, is used.

Dual-comb systems work by interfering light from two optical sources, called optical frequency combs. This mixing process generates an interferogram at a speed



that, until very recently, was too fast to be captured even by very high-speed cameras. The patented system is based on a dual-comb electro-optical source made with fiber-optic components. The main part is a dual-comb illuminator capable of generating two frequency combs that interfere at much lower frequencies than can be obtained with other systems. The speed of a measurement is less than a second, compared to several minutes required for existing systems, making real-time monitoring possible.

To date, the system has been tested for the detection and analysis of gases, as well as for studying the characteristics of different foods and materials, such as plastic, and for drying wood. The researchers are now starting to develop a system for monitoring combustion processes.

Decarbonizing cement production using solar-thermal energy

Last month, the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov) awarded $3.2 million in funding for the Solar MEAD project, which aims to decarbonize cement production. This joint project is headed by Cemex, S.A.B. de C.V. (Cemex; Monterrey, Mexico; www.cemex.com), Sandia National Laboratories (Albuquerque, N.M.; www.sandia.gov) and Synhelion SA (Lugano, Switzerland; www.synhelion.com).

Solar MEAD aims to replace the use of fossil fuels with concentrated solar thermal (CST) energy for the production of clinker — a solid material used for making Portland cement. Cemex and Synhelion have been collaborating to introduce CST in the cement production process, achieving the first successful laboratory-scale demonstrative pilot in 2022 by producing the first-ever solar clinker (for more details and a flowsheet of the process, see *Chem. Eng.*, March 2022, p. 6). Sandia Laboratories will contribute unique research facilities as part of the National Solar Thermal Test Facility, and subject matter expertise to help accelerate the adaptation of the technology to cement manufacturing.

Synhelion's breakthrough technology delivers high-temperature process heat beyond 1,500°C, which can generate sufficient heat to produce clinker without using fossil fuels. In conventional kilns, fossil fuels are typically used for heating and account for approximately 40% of direct CO_2 emissions of the process.

"Few renewable technologies are capable of generating heat at the temperatures needed to process raw cement feedstock," says Nathan Schroeder, Sandia researcher and principal investigator for the Solar MEAD project. "This project will advance our understanding of how to use concentrating solar technology to gather and deliver the heat to existing cement production facilities and will have cross-cutting relevance to other ore processing industries, such as refractory, ceramics and battery production."

Using a 'green' oxidizer to degrade Kraft lignin into vanillin

The demand for vanillin vastly outstrips the natural resources of this flavoring agent. A chemical process is thus used to produce the required large quantities of vanillin from petroleum, which is far less expensive than obtaining the substance from fermented genuine vanilla pods. Another alternative is to make vanillin from lignin, a waste product of the wood pulping industry. A team led by professor Siegfried Waldvogel of Johannes Gutenberg University Mainz (JGU; Germany; www.uni-mainz.de) has now managed to further enhance its method of electrochemical production of vanillin from lignin by using a "green" oxidation method for this purpose. This degrades Kraft lignin — a supposed worthless byproduct — to release vanillin. "We are confident that our sustainable, environmentally friendly process can contribute towards an even larger-scale production of vanillin," Waldvogel says.

The method, described in a recent issue of *Angewandte Chemie International Edition*, combines an electrosynthesis of peroxodicarbonate ($C_2O_6^{2-}$) from CO_3^{2-}. The fresh $C_2O_6^{2-}$ oxidant is then used in a separate continuous-flow electrolyzer with a boron-doped diamond (BDD) anode and stainless-steel cooling jacket that also serves as cathode. The synthesis of the $C_2O_6^{2-}$ oxidant is performed "ex-cell" because it requires a low (below 0°C) temperature, whereas the depolymerization of lignin occurs at a higher (over 100°C) temperature. With this method, the researchers demonstrated the oxidative depolymerization of Kraft lignin at 180°C to produce vanillin yields of up to 6.2 wt.%, "which is an outstanding result," emphasized Waldvogel. (The maximum yield achievable to date is 13 wt.% for nitrobenzene oxidation, which is not used commercially due to the toxicity and hazards associated with nitrobenzene). Moreover, the carbonate used is a necessary make-up chemical for the operation of cellulose plants. This means that there are various options for a technical solution of combining the process with the operation of a biorefinery.

A customized catalyst for solid-state reactions

Chemists at Hokkaido University (Sapporo, Hokkaido, Japan; www.global.hokudai.ac.jp) and the Institute for Chemical Reaction Design and Discovery have developed what is said to be the first high-performance catalyst specifically designed and optimized for solid-state, mechanochemical synthesis. The new approach was reported in the March 9 issue of the *Journal of the American Chemical Society*.

Mechanochemical synthesis, in which solid state crystals and powders are ground together (in a ball mill, for example) has advantages over conventional solvent-based methods, because it reduces the use of hazardous solvents, and can allow reactions to proceed faster and at lower temperatures. Such advantages have led to a renewed interest in mechanochemical synthesis, which was first proposed in the 1890s (see *Chem. Eng.*, December 2022, pp. 26–27).

However, because solid-state reactions occur in a very different environment than solution-based reactions, catalysts behave differently. For example, previous studies found that palladium-complex catalysts originally designed for use in solution often did not work sufficiently in solid-state mechanochemical reactions, and that high reaction temperatures were required. Using the unmodified palladium catalyst for solid-state reactions resulted in limited efficiency due to the tendency of palladium to aggregate into an inactive state. The research team designed a catalyst to overcome this mechanochemical problem of aggregation.

"We developed an innovative solution, linking palladium through a specially designed phosphine ligand to a large polymer molecule called polyethylene glycol," explains chemistry professor Hajime Ito. The polyethylene glycol molecules form a region between the solid materials that behaves like a molecular-level fluid phase, where mechanochemical Suzuki-Miyaura cross-coupling reactions proceed much more efficiently and without the problematic aggregation of palladium. In addition to achieving significantly higher product yields, the reaction proceeded effectively near room temperature — the previously best-performing alternative required heating to 120°C.

The researchers believe their approach could be adapted for many other reactions, and also for catalysts using other elements from the transition metals of the periodic table. ■

willow growth. This tackles the common criticism of many renewable energy projects, which is that land is lost from food production.

NITROGEN RINGS

An international team with researchers from the University of Bayreuth (www.uni-bayreuth.de) presents a potentially groundbreaking discovery for nitrogen chemistry in *Nature Chemistry*: For the first time, a compound containing aromatic rings of nitrogen atoms has been synthesized. The compound, K_9N_{56}, was produced under extremely high pressures and temperatures. It has a very complex structure, but its major building block is the planar ring of six nitrogen atoms, which is called hexazine anion, $[N_6]^{4-}$. The arrangement of nitrogen atoms in $[N_6]^{4-}$ is similar to that of carbon atoms in benzene, and the structure conforms to Hückel's rule for aromaticity.

Although aromaticity was initially thought to be exclusive to carbon cycles, it has since been shown that numerous systems composed of carbon heterocycles and non-carbon cycles can have an aromatic character. Nitrogen aromaticity, however, has thus far been restricted to the $[N_5]^-$ pentazolate anion.

To make the K_9N_{56}, potassium azide (KN_3) and molecular nitrogen were compressed under a pressure higher than 400,000 atm and heated to 2,000°C with high-power lasers. The structure of K_9N_{56} is composed of a complex arrangement of $[N_6]^{4-}$ and $[N_5]^-$ rings, as well as neutral nitrogen dimers.

WATER-SOLUBLE PLASTIC

The University of Alicante's (UA; San Vicente del Raspeig, Alicante, Spain; www.ua.es) Waste, Energy, Environment and Nanotechnology research group has developed a process for obtaining a water-soluble plastic based on potato starch, which will soon be introduced on the market through the UA technology-based company Solublion (www.solublion.com). This new material is said to be compostable and biodegradable, and suitable for use as a flexible film, preferably in bags and packaging. ❐

LINEUP

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ARAMCO
ARCHROMA
BASF
BP
CELANESE
COVESTRO
EVONIK
GIVAUDAN
HUNTSMAN
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SASOL
SIBUR
SOLENIS
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Plant Watch

Evonik to expand methionine production capacity in Singapore

March 9, 2023 — Evonik Industries AG (Essen, Germany; www.evonik.com) is expanding its capacity to produce DL-methionine on Jurong Island, Singapore, by 40,000 metric tons per year (m.t./yr). Following the expansion, production capacity will increase to approximately 340,000 m.t./yr. The project is expected to reach target capacity by the third quarter of 2024.

BASF begins production of bio-based polyol in India

March 9, 2023 — BASF SE (Ludwigshafen, Germany; www.basf.com) has begun production of its first bio-based polyol product in Mangalore, India. This product serves applications in vehicles, windmills, flooring and protective industrial coatings.

Covestro announces new polycarbonate capacity expansion in Thailand

March 9, 2023 — Covestro AG (Leverkusen, Germany; www.covestro.com) plans to further increase its global production capacity for polycarbonate (PC) specialty films. The company has started building new extrusion lines at the Map Ta Phut Industrial Park in Thailand. The films are used primarily in identity documents, automotive displays and electrical and electronic applications. Completion of the expansion is scheduled for 2025.

Evonik opens new lipids manufacturing line in Germany

March 9, 2023 — Evonik is opening a new facility to manufacture lipids for advanced pharmaceutical drug-delivery applications. The lipid facility is located at the company's site in Hanau, Germany and provides customers with quantities of lipids as needed for clinical and small-scale commercial manufacturing.

Momentive to build new specialty silicones site in Thailand

March 7, 2023 —Momentive Performance Materials Inc. (Niskayuna, N.Y.; www.momentive.com) announced a growth investment to build a new manufacturing facility in Rayong, Thailand. This new site will expand Momentive's manufacturing capacity to serve the growing Southeast Asian market demand for specialty silicones. The facility will be Momentive's second manufacturing site in Rayong.

BASF announces new plants to support aroma-ingredients portfolio

March 7, 2023 —BASF announced investment to build a new citral plant as part of its *Verbund* site in Zhanjiang, China. With this investment, BASF's production capacity for citral will increase to 118,000 m.t./yr. The company is also building menthol and linalool downstream plants at its *Verbund* site in Ludwigshafen, Germany. These plants are expected to come onstream starting in 2026.

Bp launches plans for low-carbon hydrogen cluster in Spain

March 1, 2023 — Bp plc (London; www.bp.com) announced plans for its green hydrogen cluster, in Spain's Valencia region (HyVal), located at bp's Castellón refinery. Led by bp, this public-private collaborative initiative is intended to be based around the phased development of up to 2 GW of electrolysis capacity by 2030 for producing green hydrogen at bp's refinery. The site's production of biofuels is expected to increase to 650,000 m.t./yr by 2030.

Covestro to build its largest TPU site in China

February 23, 2023 — Covestro plans to build its largest thermoplastic polyurethanes (TPUs) site in Zhuhai, China. When completed, the new site will span 45,000 m^2 and is expected to achieve a TPU production capacity of nearly 120,000 m.t./yr. The mechanical completion of the first phase is estimated for the end of 2025, which will enable initial TPU production capacity of 30,000 m.t./yr.

Vencorex announces new facility in Texas for specialty aliphatic isocyanates

February 22, 2023 — Vencorex (Saint-Priest, France; www.vencorex.com), a fully-owned subsidiary of PTT Global Chemical, is investing in its Freeport site in Texas to meet the rising demand for specialty aliphatic isocyanates used in the production of low-VOC polyurethane coatings and adhesives. The new facility is expected to become operational in the second half of 2023.

Celanese completes EVA expansion in Canada

February 21, 2023 — Celanese Corp. (Dallas, Tex.; www.celanese.com) announced the completion of a project to repurpose existing manufacturing and infrastructure assets to unlock additional ethylene vinyl acetate (EVA) capacity at its Edmonton, Alberta facility. The expansion provides approximately 35% incremental EVA capacity.

Mergers & Acquisitions

Solenis to acquire Diversey for $4.6 billion

March 8, 2023 — Solenis (Wilmington, Del.; www.solenis.com) and Diversey Holdings, Ltd. have entered into a definitive merger agreement under which Solenis will acquire Diversey in an all-cash transaction valued at

an enterprise value of approximately $4.6 billion. Diversey is a provider of hygiene, infection-prevention and cleaning products based in Fort Mill, S.C.

Aramco completes acquisition of Valvoline Global Operations

March 6, 2023 — The Saudi Arabian Oil Co. (Aramco; Dhahran; www.aramco.com) has completed the acquisition of the Valvoline Inc. (Lexington, Ky.; www.valvoline.com) global products business (Valvoline Global Operations) for $2.65 billion, through one of its wholly owned subsidiaries.

Solvay divests its stake in RusVinyl joint venture to Sibur

March 3, 2023 — Solvay S.A. (Brussels, Belgium; www.solvay.com) announced that it has agreed on final terms to sell its 50% stake in the RusVinyl joint venture (JV) to its JV partner Sibur (Moscow, Russia; www.sibur.ru). The agreement is based on a purchase price for Solvay's 50% stake of around €430 million. This transaction marks the final step in Solvay's strategy to exit its cyclical global PVC operations.

Archroma acquires Huntsman's Textile Effects business

March 1, 2023 — Archroma (Basel, Switzerland; www.archroma.com) announced the closing of the acquisition of the Textile Effects business from Huntsman Corp. (The Woodlands, Tex.; www.huntsman.com) in what the companies are calling a merger of equals. The Textile Effects business acquired from Huntsman will be integrated with the Brand & Performance Textile Specialties business of Archroma into a new division named Archroma Textile Effects.

Amyris to sell selected cosmetic-ingredient portfolios to Givaudan

February 27, 2023 — Givaudan International SA (Vernier, Switzerland; www.givaudan.com) agreed to acquire certain cosmetic-ingredients assets from Amyris, Inc. (Emeryville, Calif.; www.amyris.com), including squalene- and silicone-based product portfolios. Under a longterm agreement, Amyris will continue to manufacture ingredients for Givaudan to use in cosmetics.

Celanese and Mitsui form JV for food ingredients

February 27, 2023 — Celanese has signed a term sheet related to the formation of a JV focused on food ingredients with Mitsui & Co., Ltd. (Tokyo; www.mitsui.co.jp). Celanese will retain a 30% ownership stake in the JV and Mitsui will acquire a 70% ownership stake. Celanese Food Ingredients is a leading producer of acesulfame potassium sweetener, as well as sorbic acid and potassium sorbate preservatives.

Sasol and Topsoe to form SAF joint venture

February 21, 2023 — Sasol Ltd. (Johannesburg, South Africa; www.sasol.com) and Topsoe A/S (Lyngby, Denmark; www.topsoe.com) plan to establish a 50/50 JV to produce sustainable aviation fuels (SAF). The JV will develop, build, own and operate ventures producing SAF based on Sasol's Fischer-Tropsch technology and Topsoe's relevant SAF technologies. ■

Mary Page Bailey

The Protein Shift

Goals to sustainably feed a growing population with limited land resources are driving massive efforts to develop new food sources

Today, it is common to see plant-based "meat" products on the shelves of grocery stores. Although soy-based meat products have been available for decades, the number and variety of alternative protein sources are rapidly growing. Not only are traditional food companies involved in this quest for alternative proteins, but also university and research institutes around the world are working in this field, with new startup spinoff companies regularly emerging. This also means new business for equipment suppliers, who are getting involved with process development and scaleup of new protein sources.

According to a database maintained by the Good Foods Institute (GFI; Washington, D.C.; www.gfi.org), there are 1,361 companies involved in alternative proteins and 583 companies working on ingredients and equipment.

An emerging market

Nevertheless, "alternative proteins are a nascent category," according to a February 16 blog post from GFI. "Plant-based meat represents a little over 1% of the meat market in the U.S., and cultivated meat has not yet hit global markets," says GFI. (For more on cultivated meat, see *Chem. Eng.*, April 2022, pp. 14–19). "Over the past decade, the alternative proteins sector has attracted $14.2 billion in private capital, with annual investments nearly doubling every year on average … Buoyed by a slew of new products and innovations coming to market, alternative protein investments almost tripled to $3.2 billion in 2020 before surging to a record $5.1 billion in 2021," according to GFI.

Equipment-vendor news

Realizing the need for engineering and upscaling to industrial-scale protein production, international technology group Andritz AG (Graz, Austria; www.andritz.com) is strengthening its range of protein-production services. "We are thus supporting protein producers with process solutions ranging from raw materials to protein powders and extrudates," says Christian Kling, Andriz's Product Home Manager for Alternative Protein Solutions. "Combining our knowledge from the food-and-feed industry, Andritz becomes a one-stop-shop for machines, systems and engineering around alternative protein production to the market for food, pet food and feed."

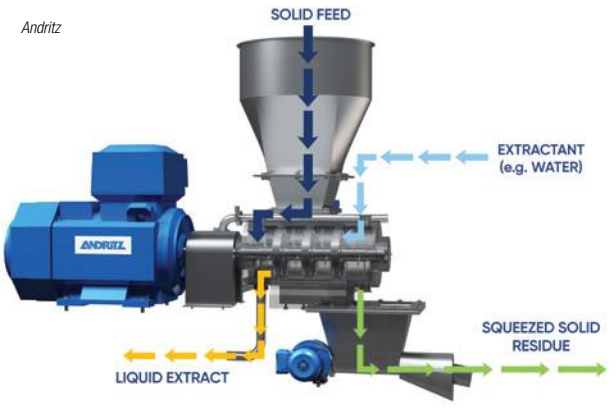


FIGURE 1. In addition to its high efficiency and lower extraction temperature, the Turbex may, in some cases, operate with water instead of ethanol as the extraction solvent, which reduces both costs and carbon footprint

For testing and validation of process lines, Andritz is investing in a 600-m^2 Food Innovation Center in Waddinxveen, the Netherlands. Scheduled to open in the second half of 2023, "this new test center allows testing all types of processes based on Andritz and other equipment — of course, under food-grade and ATEX conditions," says Kling.

"At the same time, Andritz is growing its offerings," Kling continues. "Last year Andritz launched Turbex [Figure 1] as the first step in a radical new extraction process." Turbex helps to produce high-quality extracts from botanicals and natural products and turn waste, such as orange peel or brewer's spent grain (BSG), into revenue-generating nutrients.

This patented extraction technology uses a series of rotors and stators to cause thousands of cavitation events per second, resulting in higher yields in shorter processing times. Assisted by a counter-current process, Turbex delivers yields up to 50% higher than conventional systems, the company says. The low extraction temperature combined with the short processing time improves the product quality as oxidization of valuable polyphenols and antioxidants is avoided, and requires 30% less energy than conventional extraction methods, Andritz says. "Multiple tests on different raw materials and side streams are showing impressive results and will lead to a rapid market introduction," says Kling.

Meanwhile, GEA AG (Düsseldorf, Germany; www.gea.com) established, last year, its New Food business unit (BU), which is headed by Heinz Jürgen Kroner. The new BU is mainly focused on cell-based protein production. The company also established a center of competence for bioreactors in Denmark to help meet the demand for scaling up fermentation processes.

"Many technologies needed to create alternative proteins are quite similar to those we use when producing traditional foods or even pharmaceuticals," said Kroner in a GEA report, "New Food Frontiers," published in January. "Our traditional customers in the brewery or dairy business, for example, usually come to us with a very clear and robust idea of what they want to build ... However, in this new field, which is very start-up dominated, we often deal with cus-

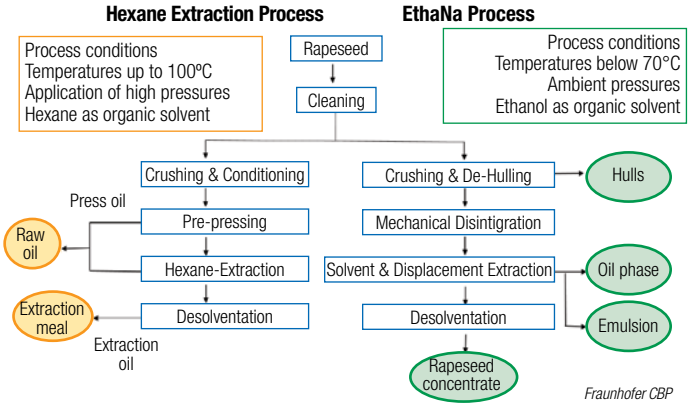


FIGURE 2. The EthaNa process was developed to pilot scale in a three-year project funded by the German Federal Ministry of Food and Agriculture and the Agency of Renewable Resources. The project, coordinated by Fraunhofer CBP, with eleven partners from industry and research institutes, was completed in February 2022

tomers who have a great idea on lab scale. They turn to us to help them bring their laboratory ideas or pilot trials to an industrial level," he said.

In 2021, Hosokawa Alpine AG (Augsburg, Germany; www.hosokawa-alpine.de) opened its Application Center Food in Augsburg, Germany, to enable users to test processes using various air classifiers and mills, which are used for dry fractionation of grains. There are several sources of protein that were previously only used for the animal-feed industry, the company says, such as sunflower meal, pseudo cereals (such as quinoa), food sidestreams from brewery processes and edible-oil extraction processes. Not only protein is interesting for dry fractionation, but so are other ingredients, such as fibers.

New business changes are also being seen in the extruder business. "Some years ago Coperion started to see a huge increase in inquiries about using extrusion technology to texturize differing unique proteins," explains John Sheehy, global key accounts manager — Alternative Proteins at Coperion K-Tron Salina, Inc., (Salina, Kan.; www.coperion.com). "In the past, when we received sales inquiries for texturized vegetable proteins (TVP), it was for texturizing soy proteins only. Then, we also started to receive additional inquiries for many other alternative proteins — especially pea and differing pulse proteins. We soon came to realize the necessity to develop a specific strategic initiative for the alternative protein market within our Food, Health and Nutrition Division."

Among those initiatives, the company made targeted investments in R&D to improve or modify its equipment to address specific needs of the alternative-protein and plant-based foods market, Sheehy says. For example, the ZSK Food Extruder in Hybrid Version is an extruder in hybrid design to process both TVP and high-moisture meat analogs (HMMA) in the same machine with only a minimum amount of retrofitting.

The company has also made improvements in cooling die technologies, particularly for use in the production of HMMA, continues Sheehy. "Within this process system, the moisture content of the end products can exceed 50%, which is comparable with the moisture content of lean meat. This high-moisture extrusion cooking process can be used for the production of meat substitutes featuring desirable sensory properties from raw plant materials with high protein content, such as wheat, soy, pea- and lupine-flour protein concentrates and isolates, he says.

Cooperation is key

Coperion also began collaborating with customers, independent research firms and academic institutions to address the important needs of the industry. For example, "Coperion made significant investments to improve our customer-testing capabilities on a global basis. This included a notable joint venture (JV) with Purdue University (West Lafayette, Ind.; www.perdue.edu) and Purdue's Food Entrepreneurship and Manufacturing Institute (FEMI) to install a GMP [good manufacturing practice] facility dedicated to the development of plant-protein extrusion and processing," says Sheehy.

Another example of a large collaborative effort is the four-year, €13.9-million project that started last November. The Like-A-Pro project, which is funded under the E.U.'s Horizon program, brings together key representatives along the entire alternative-protein value chain (protein producers, ingredient and product developers, culinary centers, food clusters), scientists and market and communication experts in a transdisciplinary consortium (42 entities in 17 countries) coordinated by the technological center CTIC CITA (Alesón, Spain; ctic-cita.es).

Like-A-Pro aims to facilitate sustainable and healthy diets by mainstreaming alternative proteins and products, making them more available, accessible and acceptable. This will be done via development of 16 new alternative protein products with ingredients from seven novel and optimized protein sources.

For example, one of the participants is the Fraunhofer Center for Chemical-Biotechnological Processes (CBP; Leuna, Germany; www.cbp.fraunhofer.de), whose task is to dehull rapeseed from local producers and then separate the rapeseed oil from the rapeseed kernels. The new EthaNa (ethanolic native extraction) process (Figure 2) is used here, which, with the help of ethanol, separates the oil from the rapeseed and extracts bitter substances from the kernel concentrate. The EthaNa process uses mild process conditions, avoiding protein denaturation, which is currently still a major problem in conventional processes. At the same time, the kernel concentrate is separated from the rapeseed oil and other bitter substances, so that no further processes are required to purify the proteins. As a result, a kernel concentrate is produced at the CBP using the EthaNa process, which has a high protein content that can be used by the project partners for food production.

Production plants and products

In January 2022, Royal DSM N.V. (Delft, the Netherlands; www.dsm.com) unveiled its new integrated Food & Beverage operating structure, which unified three areas of DSM's nutrition business — Food Specialties, Hydrocolloids and part of its Nutritional Products group. The new business

group combines the company's full range of food-and-beverage ingredients, expertise and science-based solutions that improve the taste and texture of foods.

DSM is taking strategic steps in developing specialty proteins, including CanolaPRO — a sustainable, plant-based protein source from the canola (rapeseed) plant that improves vegan and vegetarian products. DSM's recent acquisition of Vestkorn Milling, a supplier of pea- and bean-derived proteins, starches and dietary fibers, will also complement and further accelerate this growth.

Just last year, DSM announced the launch of several new products, including a next-generation cheese; Delvo Plant Go, oat-based dairy alternatives; Delvo One, its first "all-in-one cultures" for fermented milk; Vertis Canolapro, a plant-based protein, and what DSM says is the world's first textured vegetable protein that is a complete protein, soy-free and gluten-free.

Meanwhile, Archer Daniels Midland (ADM; Chicago, Ill.; www.adm.com) signed a joint-venture (JV) agreement last month with Marel (Garðabær, Iceland; www.marel.com), a leading provider of advanced food-processing solutions, to build an innovation center in the heart of the Netherlands food valley at the Wageningen Campus. Subject to regulatory approvals, the center is anticipated to open in the second half of 2024. The innovation center is designed for food manufacturers to work alongside food scientists, extrusion experts and culinary professionals to prototype, manufacture and market new alternative protein products, as well as leverage pilot-plant production with novel processing techniques.

ADM also opened a new extrusion facility in Serbia last September, and invested $300 million to expand its Decatur, Ill. alternative-protein production, as well as open a new Protein Innovation Center.

Precision fermentation

ADM also formed a strategic partnership with New Culture (San Leandro, Calif.; www.newculture.com) last fall to scale up and commercialize alternative dairy products. New Culture uses precision fermentation to produce casein, which can then be made into cheese. Animal-free mozzarella is being introduced to U.S. pizzerias this year.

In another collaboration, ADM and the Asia Sustainable Foods Platform recently started their JV company, ScaleUp Bio — said to be the first company in Singapore to provide contract-development and manufacturing-organization services for precision fermentation for food applications.

ScaleUp Bio entered a multi-year partnership with A*Star's Singapore Institute of Food and Biotechnology Innovation to establish a joint laboratory, scheduled to be operational this year. It will provide startups with fermenters that can support 100 L in capacity, associated downstream processing units and analytical equipment for process optimization. Startups can then transition to ScaleUp Bio's new facility, scheduled to be operational mid-2023, to support 10,000-L capacity.

Last month, Cargill (Minneapolis, Minn.; www.cargill.com) and startup company Cubiq Foods (www.

FIGURE 3. The Mobile Test Center (MTC) is a fully equipped, pilot-scale process line for cell cultivation or fermentation

cubiqfoods.com) signed product co-development and commercial go-to-market agreements aimed at developing and accelerating wide-scale commercialization of Cubiq Foods' fat technologies. Cubiq Foods has developed a technology platform to produce cultivated fats and omega-3-rich cell-based oils, and has new patented methods for preparing structured oil/water emulsions to replace plant and animal fats in food production.

Meanwhile, Enough B.V. (formerly 3F BIO; Zeeland, the Netherlands; www.enough-food.com) completed construction of its flagship facility last September. With initial capacity to produce 10,000 metric tons per year (m.t./yr) — one of the world's largest protein facilities — the 15,000-m^2 facility is co-located alongside the Cargill site in Sas van Gent, the Netherlands. The location and collaboration with Cargill ensure the most efficient feed source and supports the zero-waste advantages of Enough's product, the company says. The company plans a target of 60,000 m.t./yr of capacity by 2027, and 1-million m.t./yr by 2032.

Enough grows Abunda mycoprotein by fermenting fungi using renewable feedstocks to make what is claimed to be the most sustainable source of food protein, while also containing all essential amino acids, as well as being high in dietary fiber. It can be made into alternative/vegan meat, seafood and dairy products.

At last year's Anuga FoodTec trade-fair (Cologne, Germany; April 26–29, 2022), GEA unveiled its Mobile Test Center (MTC) — a fully equipped, pilot-scale process line for cell cultivation or fermentation — for new food applications. The units of the MTC can be individually configured for a given application, and serve to bridge the gap between laboratory work and demonstration plants.

The MTC consists of eight industry-approved, food-grade technologies, including the company's multifunctional fermenters or bioreactors, as well as equipment for mixing, heat treatment, homogenization, separation and filtration (Figure 3). With the freedom to alter the sequence of the various steps and add or repeat process stages, users are empowered to test cultivation and fermentation strategies, as well as product recovery. ■

Gerald Ondrey

Process Sensors: It's All About the Data

Today's process sensors provide a real-time data foundation for asset management and process optimization across the enterprise

For many decades, industrial process sensors have been used across the chemical process industries (CPI) to measure common process variables, such as pressure, level, flow and temperature. These basic measurements continue to provide the foundation for basic regulatory control, advanced process control and model-predictive control at the loop, unit and plant levels. But today, the role of process sensors is expanding beyond process control to provide a real-time data foundation for plant and enterprise asset management and digital transformation across a chemical manufacturing enterprise.

Industrial process sensors, increasingly in combination with new, low-cost industrial internet of things (IIoT)-connected sensors, now provide the diversity of process and asset-related data needed to implement the more proactive, condition-based maintenance and asset-management strategies required for digital transformation. Accurate sensor-based data are essential for developing high-fidelity process simulations for operator training and process optimization and to train expert systems and other artificial intelligence applications used to help business managers make better decisions relative to production scheduling, asset utilization, risk management, and so on. Summarizing this trend, Jack Roushey, an industry marketing manager at Siemens, comments: "Digitalization in the process-measurement portion of industries, such as chemicals, pharma and biochem, allows the data that's being collected to be more efficiently utilized in such things as predictive maintenance, developing digital twins and remote monitoring."

In recent years, process sensors and their associated transmitters have become smarter; more accurate and reliable (Figure 1); easier to commission and configure, troubleshoot and maintain; and more energy efficient. Thanks to digitalization, many field instruments now offer multiple measurements from a single device, reducing the number of process penetrations required.

Technology suppliers in the process sensor space continue to refine and enhance existing capabilities and roll out entirely new capabilities. While current trends relate largely to improved standards-based interoperability (see box on p. 19), wireless connectivity, and more sophisticated sensor self-diagnostics and remote condition monitoring and verification capabilities, some new sensor technologies are also emerging. The latter include an increasing variety of non-contacting sensors for corrosive processes, in-situ process analyzers and inferential "soft sensors."

New wireless solutions

While not a new technology, wireless connectivity between the field and plant systems has really taken off in recent years. While, in the past, wireless communications were used primarily to monitor assets or processes rather than for mission-critical process control, this too is gradually changing as technology suppliers address earlier performance, reliability, determinism, powering and security concerns. Once a reliable wireless network infrastructure has been implemented within a chemical plant or complex, wireless connectivity is often significantly more cost-effective to implement and support than wired networks. This is particularly true if field systems are located over wide areas. According to Jenny Leion, a chemical industry solutions manager at Emerson Automation Solutions, "Within chemical plants, wireless solutions will be a game changer when it comes to all these areas that are today controlled manually (or not at all) or have only local sensors."

"We're also seeing increased interest in applying 5G cellular and other traditionally 'non-industrial' wireless technologies in the chemical industry," Leion says. "Bluetooth technology, for example [Figure 2], is already commonly used to enable maintenance technicians to communicate wirelessly with field devices over short distances. Wireless technology can eliminate the need for the technician to climb to the top of a large tank, reactor unit, or distillation column to perform routine maintenance or troubleshoot an instrument."

At this juncture, all major instru-

Siemens

FIGURE 1. Advanced capabilities available in selected Siemens' pressure transmitters include higher measurement accuracy, remote diagnostics based on NAMUR 107 recommendations, and remote safety integrity level (SIL) validation

STANDARDS FINALLY COMING TOGETHER

Today's smart sensors already support bi-directional digital communications between the field devices and a control system or other host. Combined with associated software, this enables authorized operators, maintenance technicians and process or plant engineers to access device status, health, and configuration information and make needed adjustments remotely without having to physically access the devices. This dramatically reduces commissioning and maintenance time and costs, improves maintenance effectiveness, and enhances safety. Earlier concerns about unauthorized persons accessing these data or making inappropriate adjustments are being addressed through data diodes, multi-factor authentication and other cybersecurity technologies and approaches.

That said, multiple largely non-interoperable standards for both wired and wireless digital communications between field devices and process control systems remain in effect in many brownfield sites. This restricts multi-vendor interoperability, limiting choices for end users and increases complexity for users and suppliers alike. It also means that valuable asset-related data often remains "stranded" in the smart instrumentation. The situation is gradually improving with increased global collaboration between leading industry standards organizations. These organizations are working to standardize data models and device semantics, communications protocols, security mechanisms and the physical layers. These efforts appear to have broad support from both the technology end user and supplier communities.

Several announcements issued in conjunction with the recent Achema conference and tradeshow in Frankfurt, Germany in August 2022 addressed some key activities in this space. The OPC Foundation (opcfoundation.org) and FieldComm Group (www.fieldcommgroup.org), for example, jointly announced a collaboration to drive multi-vendor interoperability of instrumentation devices based on OPC UA and the OPC UA FX (Field eXchange) extensions. The goal is to provide an interoperable interface between control systems and field instrumentation.

It was also announced that the ISA100 Wireless Compliance Institute (isa100wci.org), NAMUR (the European process industries user's organization; www.namur.net), ODVA (formerly Open DeviceNet Vendors Association; www.odva.org), Profibus International (www.profibus.com), and the German trade organizations, VDMA e.V. (www.vdma.org) and ZVEI e.V. (www.zvei.org), plan to collaborate with both the FieldComm Group and OPC Foundation to complete ongoing work on PA-DIM (process automation device-information model). PA-DIM will provide standardized data access for devices whether communicating via HART, Foundation Fieldbus, Profibus PA or other standard automation protocol. Once finalized, the PA-DIM specification should enable protocol-agnostic communication of common process automation instrument parameters using OPC UA information modeling techniques. Significantly, PA-DIM incorporates the instrument parameters and semantics structure defined in the NAMUR Open Architecture (NOA) recommendations. These have broad support from chemical manufacturers in Europe and elsewhere.

Finally, Pepperl+Fuchs (Mannheim, Germany; www.pepperl+fuchs.com), which served as the technical lead, announced the completion of the Ethernet-APL (advanced physical layer) Project, which has been almost four years in the making. This collaboration between FieldComm Group, ODVA, OPC Foundation, Profibus & Profinet International, and multiple industry partners aims to make it safe and practical to use high-speed Ethernet technology to connect field devices to control systems in chemical and other plants with hazardous environments. Both BASF SE (Ludwigshafen, Germany; www.basf.com) and Procter & Gamble Co. (Cincinnati, Ohio; www.us.pg.com) have already completed successful field trials of the technology.

Ethernet communications from the field systems up to plant- and enterprise-level systems offers the potential to eliminate many of the network speed and data bandwidth constraints that have previously hampered digital transformation in the industrial space. Power over Ethernet (PoE) sensor systems are now also starting to be introduced for at least some limited use in chemical and other process plants where line power is not always readily available. For example, Emerson's (St. Louis, Mo.; www.emerson.com) MicroMotion 1600 Coriolis flow transmitter can deliver power and data over a single Ethernet cable. According to Emerson, this can save users up to 50% in installation and maintenance costs. Depending on wiring availability, the transmitter can use just PoE or have a separate direct current power input. ❐

mentation suppliers offer a full line of wireless-enabled sensors, transmitters, and other field instrumentation that conform to either the ISA 100 or WirelessHART wireless fieldbus standards. Most suppliers offer wireless tablets or other mobile devices that enable maintenance technicians to communicate wirelessly with their field instrumentation while making their routine rounds. When connected to a secure network, tablets can also be used to enable technicians to troubleshoot and resolve any issues remotely from an office or even from home.

FIGURE 2. Several leading process-instrumentation suppliers now embed short-range Bluetooth wireless communications into their process sensors and transmitters, enabling technicians to interact with the devices from a mobile device while doing their rounds. This improves safety, saves time, and helps avoid data collection errors

New, less expensive IIoT-connected sensors are also gradually making their way into chemical plants and other industrial environments, largely for asset monitoring and asset management applications. Yokogawa Corp. (Tokyo, Japan; www.yokogawa.com), for example, has introduced a family of smaller, low-cost "Sushi sensors" that make it relatively simple and cost-effective to continuously monitor key equipment operating conditions, such as vibrations, temperatures and pressures (Figure 3). These wireless, battery-powered sensors communicate with the host application via the LoRaWAN low-power, wide-area wireless data communications protocol to help improve asset maintenance and prevent failures by detecting anomalies at an early stage.

Onboard intelligence

Modern process sensors have benefited exponentially from Moore's Law. As microprocessors continue to become smaller, more powerful, and cost-effective, so have process sensors. In addition to more accurate

FIGURE 3. Yokogawa's compact, battery-powered Sushi Sensors measure vibration, temperature, and pressure for equipment monitoring purposes in industrial facilities, even those with hazardous environments

and reliable measurements, embedded capabilities today include more intuitive and comprehensive remote diagnostics and increased application flexibility. Remote partial proof testing can also be performed for some safety-related applications in chemical facilities. Taken together, these and other remote capabilities reduce the need for human workers to physically access difficult-to-reach or hazardous plant areas and improve maintenance productivity.

Like wireless connectivity, built-in remote-diagnostics capabilities on sensors and their associated transmitters is not a new concept. Starting as far back as the 1980s, leading industrial automation suppliers began introducing "smart" instrumentation with these capabilities. However, comparing those early diagnostics to what's available today, would be like comparing a Model T to a Tesla automobile. In the past, the diagnostic data were often limited in scope, almost always difficult to interpret, and could only communicate digitally to the same supplier's control systems. But as the devices became increasingly "smarter," with more powerful microprocessors, more sophisticated firmware, and better and more standardized digital communications (HART, Foundation Fieldbus, Profibus PA and others) the scope, accuracy and value of the onboard diagnostics have become exponentially more valuable.

In conjunction with appropriate asset management software, continuous onboard diagnostics allow chemical manufacturing enterprises to move from inefficient — and generally less-effective — calendar-based scheduled maintenance and/or costly reactive maintenance approaches, to far more effective and efficient predictive maintenance for their high-value assets. This is key for optimizing overall asset performance. Where needed, suppliers can also access these remote diagnostics to support their remote maintenance and asset optimization services.

Kris Worfe, Chemical Industry marketing manager at Endress+Hauser (Greenwood, Ind.; www.us.endress.com), summarized the benefits: "The advancement of smarter diagnostics has changed the game with capabilities like in-situ verification and testing. In-situ testing saves millions of dollars in maintenance by extending full-proof test intervals and calibration time. Additionally, it mitigates risk by reducing time in the field where plant personnel may be exposed to hazardous processes where there is heightened risk of accidents. This procedure also reduces downtime and unscheduled maintenance [Figure 4], helping alleviate some of the increased complexity end users face in today's industrial process environments. Lastly, it assists a smaller, less-experienced workforce that is maintaining complex applications and instruments."

What's possible

While the focus in recent years has largely revolved around exploring better ways to gain more value from the vast amount of sensor-based data that's already being generated in today's chemical processing

FIGURE 4. Endress+Hauser's Memosens 2.0 sensors for liquid analysis can store multiple data points, convert these to a digital signal and communicate them wirelessly to an associated transmitter

plants, technology suppliers continue to develop and commercialize new or enhanced sensor-based products and digitally enabled solutions.

Analyzer suppliers, for example, continue to move chemical composition analyses from the laboratory — where results typically come too late to avoid off-specification production — to online, in-situ analyzers that provide continuous online composition measurements. This also eliminates the need to extract samples. Process analyzers are also becoming easier to implement, use and maintain. According to Ryan McSherry, a product manager in Yokogawa's tunable diode laser spectrometer (TDLS) group, "As process analyzers become more reliable, there's a general shift toward applying technologies traditionally reserved for a lab setting to field devices … More and more, operating companies are looking to automate what would traditionally be manual-operator actions and to validate that automated actions taken were correct."

Some interesting advancements are also being made in inferential "soft sensors." Soft sensors combine multiple measurements (primary and/or secondary) from traditional sensors with artificial intelligence (AI) techniques and software to generate usable measurements of key variables that cannot currently be measured directly with today's technology.

While this concept is relatively new in the chemical industry, it has been widely used in other areas, including autonomous vehicles and healthcare. In experimental trials, the technology was used to monitor both chemical levels in wastewater streams and product quality, according to work presented by several scientists at Dow Chemical (Midland, Mich.; www.dow.com) in 2020.

As the CPI as a whole progresses on a path toward Industry 4.0 and digital transformation, we're likely to see many more interesting solutions emerge that will provide chemical manufacturers with the means to measure previously unmeasurable process variables online and gain more value from the thousands of different process and other sensors already installed in their plants. At the same time, it's also encouraging to see standards organizations finally coming together to effectively address many of the key pain points felt by end users across the process industries. These include lack of interoperability between the wide variety of process sensors, field networks, control systems, and host applications installed in their individual plants and across their larger enterprises. ■

Paul Miller

For details visit adlinks.chemengonline.com/84646-09

Pipes, Tubes and Fittings

Safe and reliable transport for aggressive chemicals

This company has expanded upon its proven line of SYGEF fluoropolymer piping solutions with ECTFE (ethylenechlorotrifluoroethylene), a copolymer of ethylene and chlorotrifluoroethylene, for extreme chemical applications. When materials such as polypropylene (PP), polyethylene (PE), polyvinylchloride (PVC), chlorinated PVC (CPVC) or polyvinylidene fluoride (PVDF) have reached their limits with aggressive chemicals, ECTFE is the most effective option. The high chemical resistance of ECTFE allows it to safely transport bases and highly concentrated acids, even when pH values are lower than 2 or higher than 12. Meanwhile, ECTFE's mechanical properties allow it to handle pressures up to 150 psi and temperatures up to 176°F when transporting aggressive chemicals. The company ensures the reliability of ECTFE systems through its use of advanced infrared (IR) welding technology. Fusion welding machines join the components in a consistent, repeatable, and documented manner, so that ECTFE systems offer the highest quality of piping systems. In addition to being a high-performance solution for aggressive chemicals, ECTFE is also a cost-effective system. Installation is up to 85% faster than for a comparable system of lined steel, and initial costs for an ECTFE system are typically 50% lower than they would be for IR-welded perfluoroalkoxy alkanes (PFA), the company says. The high chemical resistance of ECTFE also means lower maintenance costs, fewer process interruptions and a longer operational lifespan. — *GF Piping Systems, Irvine, Calif.*
www.gfps.com/us

Eliminate fabrication with multiport tees

In January, this company introduced new Pro-Pal Multi-Port Transition Tees (photo). The Multi-Port is a compact alternative to installing gangs of tees. It combines multiple components to save space and time, with patented technology that suits a variety of water-distribution needs. These products feature lead-free, forged dezincification-resistant brass, a selection of press or press x hose-drain run, and F1960 or F1807 PEX branches. Sizes include ¾ or 1 in., with or without reduced branches. Customization options are also available for additional sizes, connection types and accessories. — *Webstone, a brand of Nibco, Worcester, Mass.*
www.nibco.com/brands/webstone

Pipe beveler end-prep tools handle highly alloyed tubes

A family of right-angle welding end-prep tools for highly alloyed small-diameter tubes that require precision beveling prior to welding to assure high-integrity welds has been introduced by this company. The Esco Ground Millhog Beveler (photo) is a right-angle drive I.D. clamping tool that features a push-pull clamp and release mechanism that engages and disengages easily. Ideal for beveling tubes and small pipes with a high percentage of chrome, this tool produces precision welding end preps without cutting oils, and comes in pneumatic-, electric- and battery- powered models. Enabling users to achieve x-ray certifiable welds without hand grinding, the Millhog Beveler is suited for tube and pipe from 0.5-in. I.D. to 2.25-in. O.D. with 0.5-in. thick walls, and only needs a 1.5-in. radial clearance. It has totally sealed construction and can be used in any orientation. — *ESCO Tool, A Unit of Esco Technologies, Inc., Holliston, Mass.*
www.escotool.com

A new TPE tubing for biopharmaceutical applications

Last October, this company introduced HelixFlex, a high-purity thermoplastic elastomer (TPE) tubing (photo) designed for use in biopharmaceutical fluid-transfer applications. This is an expanded offering from the company, adding to its existing pharmaceutical-product portfolio of silicone tubing and components for bioprocessing,

GF Piping Systems

Webstone

ESCO Tool

Freudenberg Medical

HammerTek

drug and vaccine manufacturing, filling and sampling, peristaltic pumping, laboratory and medical-device applications. TPE tubing is suitable for pharmaceutical bioprocessing applications because it can be welded to existing tubing lines, and heat-sealed to allow for easy, fast and safe fluid transport and transfer in biopharma processes. This TPE tubing also offers many different sterilization options, including autoclave, gamma irradiation, x-ray and e-beam. Additionally, TPE tubing is a more environmentally friendly option than silicone and can be recycled. — *Freudenberg Medical, LLC, Carpinteria, Calif.*

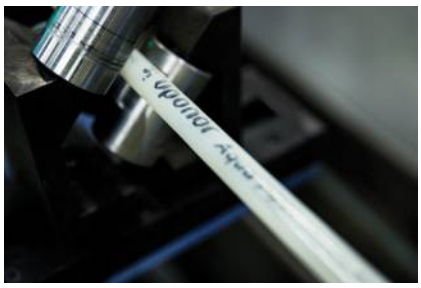
www.freudenbergmedical.com

Bee Valve

Deflection elbow kits for silo-top fill lines

New Smart Elbow Deflection Elbow Kits (photo) allow direct replacement of silo top elbows and piping or tubing that is subject to abrasive wear, with all preparation done safely at ground level. Each kit contains all components required to replace failing elbows, including two Smart Elbow deflection elbows and all necessary piping or tubing, connectors and gaskets. All can be assembled on the plant floor prior to silo-top installation, reducing personnel hazards associated with maintenance at high elevations in all weather conditions. Silo-top sweep elbows are prone to failure due to large volumes of conveyed material impacting the elbow wall at high speed to change direction, causing abrasive materials to wear through the elbow wall, resulting in blow-outs and lost production due to downtime. The Smart Elbow design features a spherical chamber that protrudes partially beyond the 90-deg flow path, causing a loose ball of airborne material to rotate in the same direction as the airstream that powers it, gently deflecting incoming material around the bend without impacting the elbow wall. In addition to preventing elbow wear and failure, the design reportedly precludes friable materials from degrading and dusting, plastics from melting and forming streamers, and heat-sensitive materials from building up and plugging, while reducing pressure drop and offload times by up to 50%. — *HammerTek Corp., Bethlehem, Pa.*

www.hammertek.com



Uponor

Two styles of hose clamps offered here

This company offers two types of hose clamp — worm-gear clamps (photo, top) or T-bolt clamps. The worm-gear clamps (photo, bottom) are available with 201 stainless-steel bands and housing and in a full range of sizes. Screws are available in 401 stainless steel or zinc-plated carbon steel. The T-bolt clamps are made from 304 stainless steel, and are suitable for high-torque applications. These clamps provide 360 deg of sealing surface, and have a band width of 0.75 in. A stainless-steel bolt with silver-plated nut is used to prevent seizing. — *Bee Valve, Inc., Elyria, Ohio*

www.beevalve.com

Making high-quality pipes from hard-to-recycle plastic waste

Together with Neste, Wastewise and Borealis, this company has successfully produced pipes made of cross-linked polyethylene (PEX; photo), which was based on feedstock gained from chemically recycled, post-industrial waste plastic from PEX pipe production, using an ISCC PLUS certified mass-balancing approach. The partner companies believe this project is among the first implementations of chemical recycling of PEX. PEX pipes are an important contributor to energy-efficient heating and safe plumbing due to their robustness, temperature resistance and longevity, yet the interconnected polymer chains make them nearly impossible to recycle with conventional recycling technologies. The cooperation sees Wastewise use their novel pyrolysis-based chemical recycling technology to liquefy industrial waste from Uponor's PEX pipe production, breaking the polymers down back into their building blocks, which creates an oil-like recycled intermediate. This liquid is then co-processed in Neste's oil refinery in Porvoo, Finland and upgraded into recycled Neste RE, a high-quality drop-in feedstock for the production of new polymers. Borealis is feeding this raw material into its steam cracker and consequently polymerizing it into PE as part of its Borcycle C chemical recycling portfolio. Finally, Uponor is using the PE to create new PEX pipe systems. — *Uponor Corp., Vantaa, Finland*

www.uponorgroup.com ■

Gerald Ondrey

New Products

A new product platform for liquid-measurement needs

The Polaris line of inline process refractometers (photo) can be used for a broad range of industrial liquid-measurement applications. Used for inline liquid-concentration measurements, this process refractometer family is said to be the first fully in-house developed refractometer series that combines both liquid and gas measurement capabilities. The Polaris series includes several dedicated models for various industrial sectors. The PR53AC is designed for hygienic applications in the food-and-beverage and life-sciences sectors. The PR53GP is designed to measure concentrations of sugars, acids, alkaline solutions, alcohols and solvents. The PR53SD measures total dissolved solids in pulp-and-paper processes. Additional models target semiconductor manufacturing, metals and mining and hydrocarbons. — *Vaisala Oyj, Vantaa, Finland*

www.vaisala.com

This new app improves CCUS process design and reliability

As industry seeks to meet their net-zero commitments, captured CO_2 must often be transported hundreds of miles to and from carbon-capture, utilization and storage (CCUS) hubs. The new CO_2 Transportation Cloud application (app; photo) enables users to make data-driven decisions to reduce risk, maintain safe operating conditions and maximize asset utilization for transportation of CO_2. To develop the app, this company conducted extensive thermodynamic studies into the behavior of impurities, such as H_2S, oxides of nitrogen (NOx) and water, in dense-phase CO_2 transportation conditions and have extended their models to accurately predict corrosive phases or solid formations in CO_2 pipelines. By democratizing first-principles-based predictive models through a simple user experience, this app can bring vital information to help organizations realize how conditions will impact operations and optimize CO_2 transportation. — *OLI Systems, Inc., Parsippany, N.J.*

www.olisystems.com/co2app

A new six-channel transmitter with easy setup and configuration

With the new 9950-10/11 transmitter (photo), this company has added a six-channel option to its 9950 product family. Additional features, such as derived functions and Boolean logic, provide expanded control options that may reduce the need for programmable logic controllers (PLCs) on small skids and systems. The intuitive menu makes the transmitter easy to operate, and relay activations are clearly signaled by the user-selectable red backlight display. Additional versatility is provided with its capability for multiple parameters through support of flow and analytical sensors. The 9950 features up to six 4–20-mA outputs, Modbus connectivity and input and outputs that are fully customizable. The line also offers a choice of sensor combinations. The 9950 is suitable for a wide variety of applications, including water- and wastewater-treatment systems, reverse osmosis, deionization, media filtration, chemical manufacturing, air scrubbers, cooling towers, aquaculture and more. — *GF Piping Systems, Irvine, Calif.*

www.gfps.com/9950

This valve is certified for use with up to 100% hydrogen mixtures

BM6X Series Slam-Shut valve (photo) has received approval by Bureau Veritas Italia for use in applications with up to 100% hydrogen and pressures up to 100 bars. The certification granted to the BM6X Series Slam-Shut valve confirms the verification of material suitability, based on internal and external seal tests performed at the company's production plant in Castel Maggiore, Italy. The Bureau Veritas procedure, relating to the issue of Type Approval for hydrogen-operated actuators and valves, defines the audit process for the issue, maintenance and renewal of the certification for actuators and valves used with hydrogen or hydrogen mixtures. The BM6X Series Slam-Shut valve has multiple applications throughout gas transmission networks, regulating stations and end-use infrastructure. — *Emerson, St. Louis, Mo.*

www.emerson.com

Vaisala

OLI Systems

GF Piping Systems

Emerson

Flowserve

PureAir Filtration

Charles Ross & Son

Advanced Microwave Engineering

These ball valves minimize leakage and emissions

Worcester 51/52 Series reduced-port flanged ball valves (photo) have been reengineered for global availability by standardizing the valves' design, materials, construction and product certifications. The bubble-tight shutoff design and robust, live-loading packings in these valves minimize fugitive emissions, enhance safety and maximize regulatory and standards compliance. Featuring a redesigned end plug, the valves ensure positive retention and greatly reduce blowout risk. Low operating torques allow for compact actuator operation, reducing space and cost requirements. Operating temperature limits are –196 to 300°C (–320 to 572°F). — *Flowserve Corp., Dallas, Tex.*

www.flowserve.com

Industry's first continuous monitoring unit for filter media

This company's Electronic Bed Media Monitor (EBMv2; photo) is said to be a first-to-market technology for measuring filtration-media consumption in real time. Through continuous monitoring and an electronic notification system, this monitor makes filtration-unit maintenance predictable and plannable. The EBMv2 features six externally wired and mounted sensors to detect changes in the life of the adsorbent media. The sensors transmit this information to a control panel that predicts a media consumption date based on a proprietary algorithm. Instantaneous readings mean that there is no sampling required, and no wait time for test results. A predictive alarm sends alerts when media is partially and completely consumed. The system also provides odor-control accuracy and system reliability. — *PureAir Filtration, Norcross, Ga.*

www.pureairfiltration.com

Protect against contamination in mixing processes

The CDA-200 multi-shaft mixer (photo) features a two-wing anchor agitator and two medium-speed agitators, each fit with five rows of three-blade pitched turbines. The mixer can be supplied with two portable stainless-steel mixing vessels and transport covers for semi-continuous operation, a 4-gal charging hopper for introducing ingredients to the batch and a thermoprobe for accurate temperature readings. All three agitators are driven independently by explosion-proof, inverter-duty motors. The two-wing anchor includes Teflon scrapers that contact the jacketed sidewall and bottom surfaces. Double FlexiLip seals and silicone O-rings enable vacuum operation up to 29.5 in. Hg for creating air-free pastes, slurries, gels and suspensions. Designed for heavy-duty use, this line of multi-shaft mixers standardizes on precision bearings with large bearing spans, which reduce agitator shaft deflection and vibration. With no bearings and seals in the product zone, the mixers are said to offer better protection against contamination compared to other designs with bottom-entering agitators. — *Charles Ross & Son Company, Hauppauge, N.Y.*

www.mixers.com

New platform makes warehouses safer than ever

Amesphere is a proprietary "safety as a service" platform designed to help companies handle safety in complex work environments in warehouses and logistics centers. The platform was first launched last month at the ProMAT Expo. Amesphere includes services for vehicle-person and vehicle-vehicle collision avoidance; real-time data collection and processing; objective and qualitative analysis of safety and efficiency; and dedicated reporting tools. Consistent software and firmware updates, remote technical support and a multi-year subscription formula make the service the first and only of its kind, says the company. The system consists of three devices interconnected via Bluetooth: a sensor, tablet and a wearable device worn by workers. Local Positioning System technology detects an operator's position relative to a vehicle with more reliable and accurate performance than any other collision-avoidance system, according to the manufacturer. This allows the system to intervene only when the level of risk is objectively high, thereby avoiding false alarms. — *Advanced Microwave Engineering S.r.l., Firenze, Italy*

www.ameol.it

This pressure sensor can take on many monitoring roles

With its all-in-one design, the DPS+ pressure sensor (photo) can act as a differential pressure switch (DPS), differential pressure transducer, pressure transducer, filter wash controller, data logger and more. The product boasts a compact size, making it suitable for monitoring and controlling pressure differences with any flow media, including water and air. DPS+ is equipped with technology that monitors flow and measures pressure differences by recording "high" (pre-flow constraint) and "low" (post-flow constraint) pressures. It uses its own microprocessor to analyze the data and activate the built-in switch, sending an electric signal when the pressure difference reaches the pre-set value. The product's transducer transmits an analog signal in response to high, low or differential pressures. — *Rotal Innovative Technologies, Kfar-Saba, Israel*
www.rotal-rit.com

Rotal Innovative Technologies

This seal stops leaks very quickly and holds for hours

RuptureSeal leak-stopping devices (photo) can be easily deployed to form a secure mechanical seal that stops leaks for up to 10 h. This technology is fully functional in just 20 s and is said to be faster and cleaner than any other leak-stoppage method, including wooden bungs or screw plugs. This fast deployment time is crucial to reduce environmental impact and cleanup costs. RuptureSeal products are available in four sizes and are compatible with over 40,000 substances. With full fuel and chemical compatibility, and an operating range of –16 to 122°F, deployment of this industrial-grade leak sealant requires no additional tools. Users simply compress the silicone pad into the rupture, pull back on the handle, and the seal is mechanically fastened in place — even on rough, unclean and splintered surfaces. — *Denios Inc., Louisville, Ky.*
www.denios-us.com

Denios

Pushing the boundaries of valve-position indication to Industry 4.0

The new ThinkTop V20 (photo) is the next generation of hygienic valve-indication units. With automation, digitalization and real-time communication, the ThinkTop V20 raises the bar on process control, making it more reliable and accurate, while saving time and money on installation, commissioning, operation and maintenance, the company says. The ThinkTop V20 is the first pure valve-sensing unit that is maintenance-free and does not require manual adjustment or programming. It enables 360-deg LED visual status indication, and also provides convenient control-room monitoring of the real-time status of this company's hygienic valves. — *Alfa Laval AB, Lund, Sweden*
www.alfalaval.com

Mary Page Bailey

Alfa Laval

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Mixing Intensity in Stirred Tanks

Department Editor: Scott Jenkins

The ability to quantify liquid motion in a stirred tank is a basic step toward understanding how mixing influences process results. Quantifying mixing according to a mixing index (MI) can evaluate and predict mixing intensity related to fluid velocities in stirred tanks.

MI provides a measure of mixing intensity in stirred-tank applications with turbulent or transitional flow. The idea of a liquid mixing index is that most of the mixing effects in a stirred tank can be related to the liquid velocities in typical flow patterns. MI is not intended to be a test for subtle differences between mixing situations, but rather a simple way of evaluating or designing mixers for stirred tanks. It tries to capture the degree to which fluid flow will promote the dispersion of dissolved solutes or suspended materials in a fluid.

For more discussion of mixing intensity calculations and background literature, see Ref. 1.

One-to-ten scale

When MI is determined, a one-to-ten scale is used to describe the fluid motion associated with mixing intensity. An MI of one is considered to be the minimum level of liquid motion capable of moving all of the liquid in a stirred tank. An MI of ten is an upper limit to intensities encountered in most industrial process applications. The difference in intensity between consecutive mixing-index values on the scale (such as the difference between an index of two and three) is about the limit of differentiation possible with any description of mixing intensity.

As with most scientific and correlated mixing results, the effects of transitional flow conditions, different liquid levels, multiple impellers, and adjustments to impeller geometry are not provided in the reported results. By focusing on a practical definition of the MI and years of experience with the method for estimating mixing intensity, calculations can be reduced to simple formulas and correction factors.

The basic idea of a mixing index comes from the article by Hicks and others [*2*]. The assumption is that by using a "pumping number" that is a function of both *D/T* (the ratio of impeller diameter to tank diameter) and Reynolds number, a "bulk fluid velocity" across an equivalent tank cross-sectional area can be calculated [*1*]. The "bulk fluid velocity" is a representation of the recirculation

Multiplying the pumping index for each impeller, times the rotational speed, times the impeller diameter cubed and replacing the equivalent tank diameter with a cube root function of the tank volume forms the basis for the MI formulation [*1*]. Rearranging the terms and pumping index numbers, coefficients can be found to calculate MI values for each impeller type.

MI guidelines and characteristics

The following are mixing characteristics for various MI values associated with stirred tanks.

MI 1–2. MI values of 1 and 2 are characteristic of applications requiring minimum fluid velocities to achieve the process result and are often applied in liquid storage applications.

Mixers capable of a MI = 2 will:

- Blend miscible fluids to uniformity if the specific-gravity differences are less than 0.1
- Blend miscible fluids to uniformity if the viscosity of the most viscous component is less than 100 times the viscosity of the other fluid
- Establish complete fluid-batch control
- Produce a flat but moving fluid batch-surface

MI 3–6. Mixing indices of 3 to 6 are characteristic of fluid velocities in most industrial mixed batches, especially those used to accomplish a physical process, such as formulations and heat transfer.

Mixers capable of a MI = 6 will:

- Blend miscible fluids to uniformity if specific-gravity differences are less than 0.5
- Blend miscible fluids to uniformity if the viscosity of the most viscous is less than 5,000 times the viscosity of the other fluid
- Suspend trace solids (<0.2%) with settling rates from 2 to 4 ft/min
- Produce surface rippling at lower viscosities

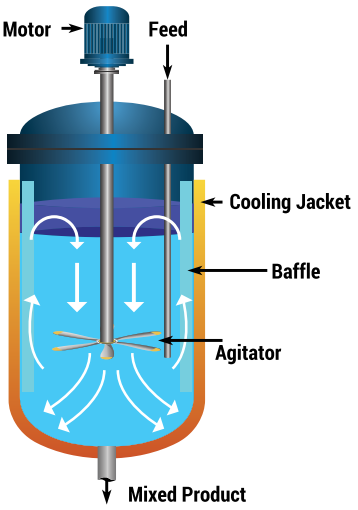

FIGURE 1. The liquid mixing index is related to the liquid velocities of typical flow patterns in a stirred tank

MI 7–10. Mixing indices of 7 to 10 are characteristic of applications requiring high fluid velocities for a rapid process result, such as chemical reactors.

Mixers capable of a MI = 10 will:

- Blend miscible fluids to uniformity if specific-gravity differences are less than 1.0
- Blend miscible fluids to uniformity if the viscosity of the most viscous fluid is less than 50,000 times that of the other fluid
- Suspend trace solids (<0.2%) with settling rates of 4 to 6 ft/min
- Provide surging surfaces at low viscosities

Process results will vary, especially if the average viscosities put the Reynolds number in the transition range. Any time the viscosity is considered to be non-Newtonian, process applications become more difficult and the effective mixing index will be reduced. No MI calculations should be taken as absolute results, but rather considered as approximations to typical industrial conditions.■

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Editor's note: the text for this column was adapted from Ref. 1.

"Pott Ash Maker": The U.S.' First Patent Holder

By David Cole, Science History Institute

Robert Fulton, Eli Whitney, Thomas Edison, Henry Ford — these are some of the larger-than-life figures who spring to mind when reflecting on the history of innovation and invention in the U.S. But the first person in American history to secure a U.S. government patent for an invention is not a household name. That distinction lies with Samuel Hopkins, a Quaker tradesman of no particular distinction who, in middle age, and at the dawn of the American republic, launched a second career as an innovator, entrepreneur and self-described "chemist." Hopkins' second career was built on his interest in what his contemporary, the American promoter and pamphleteer Tench Coxe, referred to as "a form of alchemy" — an effort that promised to be a catalyst for the early U.S. industrial economy.

Born in Maryland in 1743 (a first cousin, once removed, of the Johns Hopkins who founded the eponymous university), Samuel Hopkins identified as a "merchant" in Philadelphia until the census of 1790, when his vocation was recorded as "Pott Ash Maker." This change in professional identity was occasioned by Hopkins' timely response to the recent creation of an institution that would help transform his young country into a nation of inventors: the U.S. patent system. Anticipated in Article I of the U.S. Constitution, the first federal patent statute was passed by Congress in April 1790, authorizing the government to grant letters patents for a fourteen-year period for the invention of "any useful art, manufacture, engine, machine or device, or any improvement therein not before known or used" that could be established as "useful and important."

In 1836, a fire at the U.S. Patent Office destroyed the records of many patents sought and granted from 1790 until that date, but the one granted to Hopkins survived. Now in the holdings of the Chicago Historical Society, this document (Figure 1) was signed by President George Washington and by then-Secretary of State Thomas Jefferson (who, in that capacity, was initially charged with superintending the Patent Office and examining patent applications). The document certifies Hopkins' patent for "An Improvement … in the making of Pot-ash and Pearl-ash by a new Apparatus and Process."

FIGURE 1. The first patent issued in the U.S. was for a new process for making and refining potash

'Principal industrial chemical'

Potash (potassium carbonate) has been described by the historian William L. Roberts as "the principal industrial chemical of the 18th century." Through variations on a simple process familiar to American farmers of the period, timber that was not suitable for fuel or building material was burned in large cauldrons or "pots" (hence the name, "pot-ash," often hyphenated during this era). The resulting ashes were blended with water and heated, producing a residual black substance. Further heating to remove additional impurities yielded "pearl ash," a more refined product. Drawing on large quantities of timber harvested from the northern U.S., numerous independent producers of pot and pearl ash addressed burgeoning demand for these products in the manufacture of soaps, glass, fabric dyes, saltpeter and detergents, among others. Potash was also a significant American export good in the 18th and 19th centuries, and its value in domestic and foreign markets, coupled with the low costs and barriers to entry in its production, induced many American farmers and tradesmen to supplement their primary incomes with potash asheries.

Into this "potash boom" stepped Hopkins, whose patent claims rested on a key improvement to the traditional potash-making process — "burning the raw ashes previous to their being dissolved and boiled in water." Furnaces built according to Hopkins's patent specifications purportedly would generate 50% more pearl ash from a given yield of raw ash than would common methods of leaching and boiling the residual "black leys."

On the heels of securing his patent, Hopkins produced a pamphlet extolling the technical virtues and profit-making potential of his method, with the aim of licensing the technology to the thousands of potash/pearl ash producers already operating in the U.S. and Canada. He obtained testimonials to the superiority of his method from leading scientific figures of federal-period Philadelphia, including Caspar Wistar and Benjamin Rush, whom he described as "well acquainted with chemistry."

Traveling across the northern U.S., Hopkins pursued collaborative ventures with large landowners (such as the speculator Robert Morris), who sought to generate income from newly acquired, timber-rich holdings. Charging hefty licensing fees, and constructing his potash works for as much as $200 per works, Hopkins banked on the assumption that substantially increased yields of high-end pearl ash would justify the large initial capital expenditures that licensees would need to invest in his technology.

Sadly for Hopkins, most potential customers remained wedded to less efficient, but less capital-intensive, traditional production methods. In the years before his death (most likely in 1818), Hopkins left Philadelphia as an entrepreneurial failure, reliant on his children in New Jersey for material support. But while Hopkins' invention was not a financial success, he forged a legacy as the first American — and first chemist — to obtain a patent. The "Pott Ash Maker's" place in inventing history is secure. ■

Editor's note: This column was authored by David Cole, president and CEO of the Science History Institute (Philadelphia, Pa.; www.sciencehistory.org).

Electrification of Industrial Facilities

Manufacturing complexes may benefit from using more electricity instead of steam and fuel gas for their energy needs. Improved energy efficiency, lower emissions, higher reliability and debottlenecking of utility systems may be achieved

James Turner, Ma Katrina Sanaie and Mohamad Fakhreddine
Fluor Enterprises

IN BRIEF

WHERE TO BEGIN
ELECTRIFICATION OPTIONS
HEAT PUMPS
ELECTRIC HEATERS
ELECTRIC MOTORS
ELECTRIFICATION SYSTEM IMPACTS
ELECTRICAL INFRASTRUCTURE
STEAM SYSTEMS
WATER SYSTEMS
FUEL-GAS SYSTEMS
FLARE SYSTEMS
ELECTRIFICATION CONSIDERATIONS

Electrification is a popular buzzword when energy transition is discussed. It can have many different meanings, and depending on the subject, it can refer to the private and business transportation fleet (cars and trucks), public transportation (buses and trains) or manufacturing and industrial processes and facilities.

In process facilities, replacing steam and fuel gas with electricity can provide many benefits, from improvements in reliability to avoidance of boiler-upgrade projects to lower overall emissions. In short, if the carbon footprint from the electricity production is lower than the carbon footprint from producing the energy that is replaced by electricity, then there will be a decarbonization benefit from the electrification.

This article discusses how electrification can impact a process-focused industrial complex, such as a chemical plant or petroleum refinery, and it specifically focuses on applying electrification to existing industrial facilities.

WHERE TO BEGIN

There are several questions or issues owners or managers of existing industrial facilities may have when considering electrification of their facilities (Figure 1).

Is the facility operating at its peak energy efficiency? Many operators see a noticeable improvement in their energy intensity index (EII) from electrification of existing steam-turbine drivers. The calculations are based on efficient grid-electricity production, such as from renewable sources, compared to less-efficient boiler steam production.

Improvements in energy intensity are often a part of a facility's strategic plans and goals, which can have a noticeable impact on its operating costs.

Are the steam-generating systems and turbines in the facility becoming obsolete, and now require ever-growing maintenance needs? Owners may have planned steam-boiler replacement projects or other equipment maintenance or upgrades. If so, owners may want to consider if this investment may be better spent on electrification. Overall equipment reliability may increase and there may be environmental credits or rebates that can be availed with electrification projects.

Is the facility in compliance with local regulations on pollutant emissions? Owners may be facing looming environmental regulations that will require significant investments, such as installation of selective catalytic reduction (SCR) systems for steam boilers or process heaters, to avoid paying hefty fines. An electrification project can reduce steam demand and potentially allow the shutdown of older steam boilers, therefore reducing the cost of any required environmental upgrades. The emissions reductions from the decrease in steam demand resulting from electrification can also be used to offset an increase in emissions from other process heaters with process changes that can be valuable for other strategic goals.

Are the utility systems at capacity, or

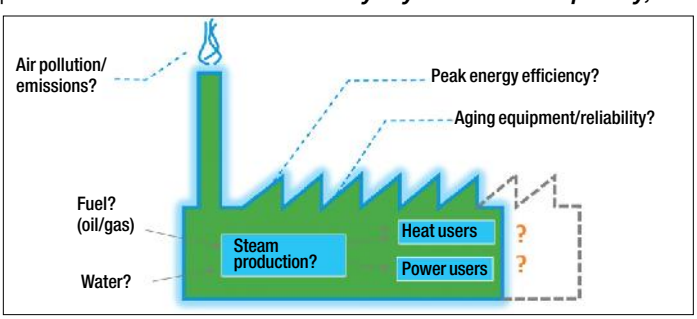

FIGURE 1. There are many questions or issues that owners or managers of existing industrial facilities may have when considering electrification of their facilities

worse, out of balance? If steam, cooling water or natural gas supply are limited in the facility, it may not be possible to expand or carry out other projects without doing some electrification projects. If the cost to purchase or produce electricity is lower than importing natural gas, then electrification can reduce operating costs.

Is there a need to re-balance the steam and electricity usage, but there are concerns about what to do with excess fuel gas? There are potential synergies in executing an electrification project coupled with a project to increase liquefied petroleum gas (LPG) recovery from the fuel-gas system. Burning less fuel translates into less CO_2 generation, which is a strategic driver for many companies. By recovering more LPG and heavier material from the fuel-gas system and replacing it with natural gas, CO_2 emissions will be further reduced, even if the fired duty does not decrease. In most markets, the revenue from the sale of LPG products and other liquid products is more than the cost of additional import of natural gas, so there can be financial benefits in addition to CO_2 reduction.

Does a facility-wide energy optimization sound intriguing, but also intimidating? If the owner is planning a strategic reconfiguration based on market-driven feed or product changes, that may be an opportunity to replace aging steam-driven compressors with new motor-driven compressors that have a fit-for-purpose duty specification.

ELECTRIFICATION OPTIONS

Once these questions have been considered, operators can begin to weigh their options. For industrial processing facilities, there are three primary electrification options, described below:

- Heat pumps replacing reboilers or condensers for distillation columns
- Electric heating or electric boilers replacing steam or fuel-fired heaters
- Electric motors replacing steam-turbine drivers

These options can have significant impacts in the right situation. Table 1 summarizes the potential impact of the different options to a facility. They are discussed individually in the following sections.

TABLE 1. IMPACT OF ELECTRIFICATION ON PROCESS OPERATIONS

IMPACTS	Heat pump	Electric heating	Electric boiler	Electric motors
Fuel consumption	↓	↓	↓	↓
Emissions	↓	↓	↓	↓
Water consumption	↓	↓	–	↓
Steam requirement	↓	↓	–	↓
Equipment efficiency	↑	↑	↑	↑
Electricity demand	↑	↑	↑	↑
Temperature controllability	↓	↓		

Heat pumps

Heat pumps use a compressor to compress a lower-temperature vapor stream to a high-enough pressure that the condensing temperature is above the temperature required to recover the heat in a traditional heat exchanger. Historically, this design has been called a heat pump, but has also been called mechanical vapor recompression (MVR). This scheme can be used for distillation columns where the column overhead is compressed to a high enough pressure to provide the heat to reboil the bottom of the column. It is also possible to design a distillation heat pump with a separate fluid in a closed loop that is compressed, condensed in the reboiler, further cooled by dropping the pressure across a valve, and then used to cool the overhead condenser. Most examples in the industry use the overhead vapor as the heat-pump fluid, as shown in Figure 2.

Heat pumps can have significantly better energy efficiency than traditional reboiler or condenser systems, with savings on both the reboiler side (which often contains steam) and the condenser side (which often contains cooling water). Energy-intensity reductions of up to 90% are reported in the literature.

Heat pumps work very well for columns that do not have a large temperature difference between the top and bottom of the column. Propane/propylene splitters, ethane/ethylene splitters (such as in steam-cracker units), and isobutane/*n*-butane splitters are good candidates for heat pumps. There are also applications in aromatics complexes and methanol production.

For most other distillation separations used in refineries and petrochemical complexes, the much larger temperature change across the column significantly reduces the value of the heat-pump approach and makes it impractical.

Heat pumps are best suited for a new design, as it would require a major revamp to retrofit an existing column with a heat pump. This option can reduce consumption of fuel, steam and water, reduce emissions and improve efficiency at the cost of a higher electricity demand.

Electric heaters

There are two ways to electrify steam or fuel-fired heaters, as follows:

1. Replace a steam heater with an electrically heated exchanger
2. Replace a fuel-fired steam boiler with an electric boiler

To convert a steam-heated exchanger to an electric heater, the steam and condensate piping and controls are replaced with electrical supply, which may reduce maintenance costs and capital costs for a new facility. An advantage of a steam exchanger is that the maximum temperature is self-limiting, meaning that the process fluid cannot be heated to a temperature higher than the condensing temperature of the steam. An electric heater will not have the same intrinsic feature, and controls must be designed to provide protection against overheating the process fluid for upset, low-flow and blocked-in scenarios.

Like the heat pump, this option can reduce fuel, steam and water consumption, reduce emissions and improve efficiency, while increasing power consumption and potentially reducing process-temperature controllability.

Another way to electrify heaters is to replace a fuel-fired steam boiler with an electric boiler. This may be a good option for a revamp of an existing facility because this option reduces emissions from steam generation while still supporting existing process-steam demand, including steam-injection and steam-heating needs.

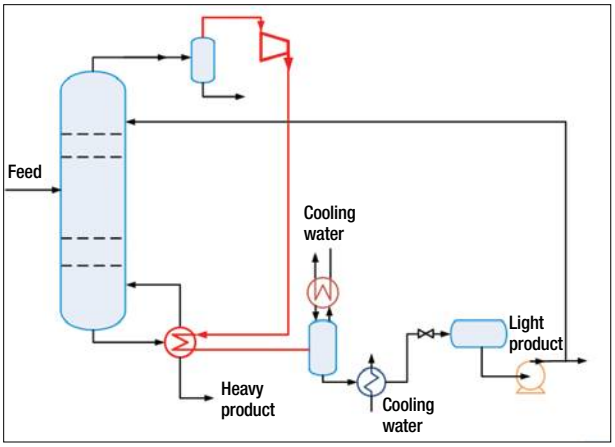

FIGURE 2. A typical heat-pump system on a distillation tower is shown

Electric motors

Several facilities have had positive results from replacing steam-turbine drivers with electric motors. Improved energy efficiency, reduced emissions, improved reliability and lower water consumption have been observed, and some sites have avoided additional steam-boiler investment. The project can impact the power infrastructure, steam, fuel-gas and cooling water systems, as well as potentially impacting process controls and relief systems.

If installing a new pump or compressor, consider if an electric motor is a viable option, even if the previous or typical driver for the service was a steam turbine.

If a facility decides to replace an existing steam turbine on a compressor or pump with an electric motor and there is adequate plot space available, installation of a new pump or compressor along with the replacement motor may not cost more when factoring in the cost savings of doing construction outside of the turnaround. Installing a new pump or compressor also replaces an older pump or compressor that can be optimized for current operations and may result in reduced maintenance and operating costs.

Steam-turbine drivers are often used to drive large compressors. Steam-turbine drivers have an inherent ability to change speeds, which can provide more flexibility and operability for the compressor to manage changes in gas molecular-weight and flow requirements. When considering switching an existing steam turbine driver to an electric motor, a decision will need to be made whether a variable-speed driver is required or if a fixed-speed driver can be used. If a fixed-speed driver is used, the impact on the compressor operation will need to be considered. If the gas molecular weight varies significantly, the compressor capacity and discharge pressure can vary at a fixed speed, potentially causing process and equipment design pressure issues. Relief scenarios and flare loads may also be impacted. Figure 3 and Table 2 illustrate some of the process impacts of motor speed.

Energy consumption may increase in some cases due to excess flow or pressure now produced by the motor-driven compressor. The suction throttle valve and spillback valve may need to be modified or replaced to provide the flexibility that was previously provided by varying the turbine speed.

If a variable-speed driver is required, consider installing a variable-speed motor or installing a fixed speed motor with a variable speed gear box. Installing a variable-speed motor may be an option, but may have a higher cost and larger space requirement for large motors. A better option may be to install a variable-speed gearbox to convert a fixed-speed motor to different speeds as required to optimize the compressor operation.

A knowledgeable engineering team should be consulted to study the impacts of electrification and propose mitigations.

Example: Replacing a steam turbine with a fixed-speed motor. There are two main types of steam turbines — condensing and backpressure. There are also condensing turbines that extract steam at one or more intermediate pressures.

Condensing turbines exhaust steam at a very low pressure — well below atmospheric pressure. The exhaust steam is then condensed, usually in cooling-water exchangers, although air coolers are sometimes used.

Backpressure turbines take a relatively high-pressure steam, as an example, 600 psig, and exhaust it at a lower pressure, for instance, 150 psig. Since backpressure turbines extract less energy from the steam compared to a condensing turbine, more steam is required for a backpressure turbine compared to a condensing turbine producing the same driver load. Table 3 shows an example of how steam demand can be reduced with electrification of an existing steam turbine.

ELECTRIFICATION SYSTEM IMPACTS

For any project, capital cost is an important factor — and often the deciding factor on the feasibility of a project. But there are other factors that should be considered to fully and properly evaluate the impact of an electrification project to the facility. For an electrification project where steam-supplied energy is being replaced by electricity, the obvious impacts are to the steam system and power supply. Any electrification project is also likely to have secondary impacts to other utilities and systems.

Electrical infrastructure

Electrification will directly impact the electrical system. The existing electrical infrastructure may indeed have the necessary spare capacity to supply the additional power load. However, the reality is that most facilities have limited or no spare capacity, thus requiring some new infrastructure, such as new substations or upgrades to the existing infrastructure.

Electrification loads can range from 5,000 to 20,000 hp, and can be even larger in some cases. Motors of this size have a significant impact on the electrical system, which needs to be studied carefully, as most facilities were not originally designed to support these large additional loads. The following are three key electrical-system studies to be performed to assess the existing electrical infrastructure:

- Load flow — to check capacity of existing equipment to support the new loads
- Short circuit — to check if existing equipment is rated to support additional motor short circuit contribution

TABLE 2. PROCESS IMPACT FROM OPERATING SPEED — CENTRIGUAL COMPRESSOR DRIVER
Existing steam turbine
3,300 rpm with discharge at 140 psia
Fixed-speed motor available
3,600 rpm with discharge at 160 psia
3,200 rpm with discharge at 120 psia
Process alterations may be required
Variable-speed motor available
3,300 rpm with discharge at 140 psia

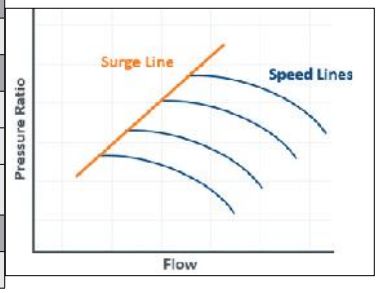

FIGURE 3. Electrification can have a significant impact on processes when considering the available motor operating speeds

- Motor starting — to check if the new motor can be started without impacting the system voltage

These are complex studies that can be performed by an experienced electrical engineer using commercially available electrical-analysis and simulation software, such as ETAP, SKM and Power Factory.

One consideration in starting large motor loads is to apply reduced-voltage starting methods using an autotransformer, capacitor, reactor or even an adjustable-speed drive. Each of these motor-starting schemes have different capital costs, so it is important to evaluate the best option that fits the mechanical or process needs of the load.

Upgrades to the existing electrical infrastructure may include additional utility power, including new transmission lines to take delivery of power at a higher voltage or expanding the site's cogeneration plant for more power generation (if the facility has one).

The new electrical configuration will impact equipment in both the main and unit substations. Most likely the transformers, switchgear and other power equipment will require upgrades. The new electrical system will likely have dedicated substations for these large loads.

There may also be an impact to the facility's underground and above ground electrical infrastructure, as well as remove the associated effects on pipeways and other structural needs to support the new conduit or trays that will feed the new loads.

Lastly, the design must consider construction and cutover challenges. If electrification is done in an existing operating facility, the electrical upgrades need to be well planned. Electrical work requires equipment to be de-energized, so the tendency is to schedule that work during a turnaround (TAR) or during scheduled maintenance to minimize the impact to the operating facility, which may impose a significant constraint on the project schedule.

Steam systems

The electric motors will reduce steam demand when replacing steam drivers. However, it is important to understand the overall impact to the steam balance at the various

TABLE 3. EXAMPLE — REDUCING STEAM DEMAND IN A 12,000-HP COMPRESSOR		
Backpressure steam turbine	**Condensing steam turbine**	**Motor**
600 psig steam source	600 psig steam source	382 A at 13,800 V (three-phase)
150 psig steam back-pressure	135,000 lb/h steam	98% efficiency, power factor = 1.0
318,000 lb/h steam	125 million btu/h fired duty	9.1 MW consumed
	7,500 gal/min cooling water	

steam levels. If the facility is long on low-pressure steam, electrification of a backpressure steam turbine will reduce production of excess low-pressure steam. Conversely, if the facility is short on low-pressure steam, electrification of a backpressure steam turbine may not have much value, since the steam saved from electrification will just shift to the high-pressure to low-pressure steam letdown station to balance the low-pressure steam demand.

Electrification of a condensing turbine reduces high-pressure steam demand, which is usually generated in steam boilers. For most facilities, this can be a significant benefit.

Water systems

Reduction in steam demand leads to a reduction in the boiler-feedwater demand, including reduction in treated-water makeup. Water consumption is often a major expense for an operating facility, so this reduction may have a large impact.

The cooling-water system can also be impacted by an electrification project. Many large steam turbines are condensing turbines, which usually have large cooling-water surface condensers. Replacing a condensing steam turbine with an electric motor can lead to a significant reduction in cooling-water demand, which debottlenecks the cooling-water system, potentially supporting other projects that would increase cooling-water demand, and reduces cooling-water makeup consumption. In some cases, an entire cooling tower, or cooling-water pumps, may be shut down, reducing power consumption as well.

Electrification of a condensing steam turbine, however, eliminates production of vacuum condensate, which is often used by some processes. In such cases, an alternate source of clean water will need to be made available for these users.

Fuel-gas systems

The fuel-gas system will frequently be impacted during electrification activities. Fuel-gas consumption is reduced if fired heat is directly replaced by electricity. Likewise, if steam is replaced by electricity, fuel-gas consumption at the steam boilers is reduced. This is beneficial if the fuel-gas system is supplemented by purchased natural gas, because electrification will reduce natural-gas usage, but could be an issue if the facility is long on fuel gas.

Many facilities run close to fuel balance and will be long on fuel gas with major electrification changes. If this is an issue, there may be options for recovering more LPG range and heavier material from the fuel-gas pool, or potentially modifying process-unit operations to produce less fuel gas.

Projects to increase C3+ recovery in gas plants can have a very good payout in selling more LPG product, in addition to the benefits of electrification. If this option is pursued, product storage and transfer logistics will need to be understood so all potential project requirements are addressed.

It may be possible to reduce the amount of heavy material that ends up in the fuel-gas system by making changes in conversion units, such as hydrocrackers and fluid catalytic cracking (FCC) units. Catalyst or operating condition changes can be considered for production of less light-end content from cracking, which ultimately end up in the fuel-gas system.

The potential impact to the fuel-gas heating value should be evaluated with the reduction of LPG material in the fuel gas. Replacing LPG with natural gas high in methane will lower the fuel-gas heating value, and there may be heaters that will experience fuel-gas hydraulic issues with a lower average heating value.

Flare systems

Another impact to consider is to the flare system. The flare load may possibly increase during a local or total power-failure scenario if a turbine-driven pump or compressor not considered to fail previously is replaced by a motor. Conversely, if a steam heat exchanger is replaced by an electric heater, a power failure would cut the heat source that could potentially reduce the total relief load. Total power failure case is often the controlling scenario for the design of the flare and relief header system. Thus, this may be an important factor to consider in the case for electrification.

Electrification considerations

So how can an operator determine what to do?

The first step is to develop an accurate power, steam and fuel-gas balance for the facility. Consider upset and other operating cases, such as when individual units are shut down for maintenance.

Operators should also understand the reliability of the existing systems and what outages will have a large impact on operations.

It is also important to evaluate the planned project portfolio for the facility, to look for cases where projects can facilitate, or be improved by, including electrification as part of the project. As an example, if there are steam-boiler replacement or reliability improvement projects, or pump or compressor replacement projects, there may be synergies for considering electrification as part of those projects.

Understanding the costs for incremental power purchase and import natural gas is helpful. Operators should become knowledgeable about the upgrades the existing systems within the facility will require with an electrification project — but they should also be aware of possible infrastructure impacts to the "across-the-fence" electrical supplier, such as the utility company.

Another crucial factor that must be considered is which current or future emissions requirements (including carbon footprint) impact the facility and would need to be resolved. These could be regulatory-driven or internal company requirements.

For example, if the existing steam boilers will require the addition of NOx-removal equipment, electrification may provide an opportunity to build new, smaller, more efficient and more reliable steam boilers for not much more than the regulatory revamp cost. Similarly, if there are steam-boiler reliability upgrade projects planned, decreasing steam consumption instead of implementing a boiler replacement or reliability upgrade project may be a better option.

To find the best project for the facility, start with high-level goals, develop a good understanding of the existing systems, and compare options while understanding which parts are independent that can be evaluated individually and which parts are interrelated and need to be considered as a group.

Clearly, both benefits and costs must be understood.

The potential benefits include:

- Reduction in operating cost
- Improvement in energy efficiency
- Reduction in emissions

Associated costs include:

- Capital cost to implement changes
- System upgrades required (both within the facility and by third-party suppliers)
- Process inside battery limit (ISBL) and outside battery limit (OSBL) impacts, both positive and negative, for each option

Finally, note that it does not help if a preliminary study makes an option look promising, but impacts that were not initially considered make the option much more expensive or impractical. ■

Edited by Mary Page Bailey

Authors

James Turner (james.turner@fluor.com) is an executive process director in Fluor Corp.'s Sugar Land, Tex. office. He has more than 30 years of experience in process design for a wide range of projects in the petroleum refining, chemicals and gas-processing industries. He has published and presented many technical articles about process design, project execution, energy transition and decarbonization, and holds patents for a combined hydrotreater process design. He is a graduate of Texas A&M University with a B.S.Ch.E. He currently serves on the Texas A&M Chemical Engineering Department Industry Advisory Council, and has been inducted into the Texas A&M Chemical Engineering Academy of Distinguished Alumni.

Ma Katrina D. Sanaie (ma.katrina.sanaie@fluor.com) is a principal process/specialty engineer in Fluor's Aliso Viejo, Calif. office. She has more than 20 years of experience in the process design of utilities and offsites for a wide range of projects in the petroleum refining and gas processing industries, and a subject matter expert in flare systems and utilities and offsites. She holds a B.S.Ch.E. from the University of the Philippines and is a registered professional engineer in California.

Mohamad Fakhreddine (mohamad.fakhreddine@fluor.com) is a process engineer located in Fluor's Long Beach, Calif. office. He has more than 15 years of experience in process design for a wide range of projects in the petroleum refining, utilities and offsites and power-generation industries. He is a graduate of California State Polytechnic University - Pomona with a B.S.Ch.E.

Incremental Electrification Drives Sustainability

For decarbonization of chemical processing sites, electrification opens a new world of efficiencies and cost benefits

Poonam Narang and Shailesh Chetty
Schneider Electric

IN BRIEF

UNDERSTANDING EMISSIONS
THE CALCULUS OF ELECTRIFICATION
LOOKING AT PROCESS SPECIFICS
IDEOLOGY BARRIERS
A MINDSET SHIFT

The industrial sector is responsible for one-third of the world's end-use energy consumption, according to data from the U.S. Energy Information Administration (EIA; Washington, D.C.; www.eia.gov) [*1*]. Within that sector, the manufacturing industry emits 20% of the world's carbon dioxide emissions [*2*]. Optimizing industry energy use will be a pivotal component of global strategies to limit greenhouse gas emissions and reach climate-saving goals.

The chemical industry is the second-largest consumer of energy within manufacturing sectors, according to EIA [*3*]. Chemical processing plants use natural gas and other energy sources to convert raw materials into a variety of products. Electrifying chemical engineering processes can be a cornerstone of emissions-reductions initiatives moving forward.

Electrification has the potential to significantly reduce reliance on fossil fuels and improve the sustainability of chemical manufacturing by replacing fossil-fuel-based processes with electricity generated by renewable sources — an obvious benefit for the environment (Figure 1). But the use of renewable electricity sources can also reduce the volatility and uncertainty associated with fossil-fuel prices, making the production of chemicals more predictable and cost-effective.

Understanding emissions

A first step in decarbonizing industrial or chemical facilities is understanding emissions. Emissions are grouped by type or scope and must be addressed according to their classification. There are three scopes of emissions per the Greenhouse Gas (GHG) Protocol (www.ghgprotocol.org), illustrated in Figure 2.

Scope 1 emissions are those emissions an organization is directly responsible for generating. Common examples include large compressors or pumps driven by gas or steam turbines and onsite sources of heat or power generation, such as boilers.

Scope 2 emissions are those emissions resulting from the grid-sourced generation of power. These emissions are considered outside the direct responsibility of the industrial facility (since it is the utility operator who determines the energy mix), but the company is still responsible for these emissions, because they are driven by demand.

Finally, Scope 3 emissions are all other indirect emissions. This broad category includes everything from the emissions generated through waste management to those generated in the value chain. For many cases, Scope 3 emissions not only make up the highest amount of a site's total emissions footprint, but are also the most difficult to address.

The calculus of electrification

Industrial activity is a major contributor to GHG emissions. There is no one-size-fits-all solution to meet net-zero emissions targets, but rather countless opportunities for innovation. It can be said that electrification of assets requires a careful calculus.

There are two categories of processes that can be electrified that are the main consumers of energy in any industrial plant — motion-related processes and heat-related processes.

Scope 1 and 2 emissions can be optimized through a hybrid energy mix. Furthermore, zero emissions from power generation can be achieved via substituting energy from fossil fuels with "clean" energy sources. Process electrification and net-zero power-management hubs can help users in managing their energy mix, which in turn optimizes emissions.

A survey from 2020 found that 44% of energy consumed in industrial settings is fuel consumed for energy [*4*]. This includes generation of heat for processes like melting and cracking. Ref. 4 also estimates that 50% of

that heat could easily be replaced with electric solutions that are available today. The concept of electrification in chemical manufacturing plants, then, is not about completely changing every process altogether. It's about proper peaking and placing, especially for those processes that operate at temperatures less than 1,000ºC.

Electric motors and machines are often smaller, lighter weight, require less maintenance and have longer lifespans than traditional combustion systems. Electrified assets, therefore, are typically more cost-effective and use much less power than their fossil-fuel-burning counterparts. Manufacturers can also digitize electricity-powered assets, combining them with predictive solutions to reduce downtime and total cost of ownership. Full to partial electrification of processes can be achieved with three options, which are discussed in further detail in Part 1 of this Feature Report, Electrification of Industrial Facilities (pp. 28–33):

1. Using heat pumps instead of reboilers and condensers
2. Using electrical heating instead of steam or fuel-fired heaters
3. Using electric motors instead of steam or gas turbines
4. Using electrical boilers for process steam needs instead of coal-fired boilers

In these instances, commercial solutions already exist, and they do not necessarily require a significant process change. Chemical manufacturing organizations can focus on electrification as a series of quick wins, replacing a boiler or furnace running on conventional fuel within electric arc furnaces or powering compressors and pumps with electric motors, rather than as an all-or-nothing solution.

Looking at process specifics

A typical study to electrify a process can be outlined in five key steps [*5*]:

1. Assess the current state, the energy demand and electrification opportunities
2. Identify available solutions and study their fit
3. Study implications through the full power system design
4. Optimize electrical architecture
5. Evaluate net impact and continue the cycle

In one case, a manufacturing organization was able to reduce about 100,000 metric tons of carbon dioxide equivalent (CO_{2e}) emissions each year by switching from gas-powered turbines to more electrically driven solutions for large compressors and water pumps. The industrial facility's energy needs were optimized by having a centralized power-generation and waste-heat recovery unit. With careful consideration of process needs, electrical drives were installed, which further optimized overall energy needs, creating cost savings in the process. Delving into more specifics helps exemplify how chemical manufacturing plants can electrify operations.

Steam cracking is a crucial process in chemical production. It's also a large CO_{2e} emitter, accounting for more than 300 million tons of emissions annually [*6*]. Steam cracking of hydrocarbons continues to be one of the main industrial processes employed to produce light olefins, building blocks for plastics, adhesives and detergents. Steam crackers operate at high temperatures (around 850ºC) to convert liquid or gaseous hydrocarbons into olefins.

While the technology to produce that kind of temperature using renewable energy sources is still being finalized, chemical manufacturers can begin planning to either retrofit existing steam crackers or replace gas-fired burners with electric heating systems. BASF SE (Ludwigshafen, Germany) and its partners recently began construction on a plant with "large-scale electrically heated steam-cracker furnaces" that will reach the 850ºC needed for continuous olefin production [*7*]. For less heat-intensive processes, electric heat pumps and boilers are available today that can take demand up to 350 to 400ºC. Electrification can also enable the use of carbon-free feedstocks for chemicals, which can further reduce the carbon footprint of chemical manufacturing processes.

Ideology barriers

Despite the many potential benefits of electrification, there are also challenges to its widespread adoption in the chemical industry. In fact, the industrial sector is considered one of the most difficult to electrify, in large part due to the complexity and diversity of its processes [*8*]. Add to those complexities worries about grid resiliency, and it is easy to see why chemical manufacturers stick with what is already working for them. The industry's inertia comes from reasonable trepidation about mounting complexity, as well as technological, economic, regulatory and safety-related challenges.

Although many of the essential technological elements for electrification exist or are on the verge of being commercialized, every process requires tight integration with new assets and solutions and with other processes. Integration requirements can cause complexity to balloon because any process change creates a cascade of effects into various others. For example, researchers point to the fact that "using ethane from natural gas in steam cracking instead of naphtha from petroleum increases ethylene yields at the expense of lower propylene and aromatics yields [*9*]."

Moreover, converting electricity into heat and eventually chemical products is not currently an efficient or cost-effective process, as the steam-cracking example highlights. The good news is that plenty of technologies are moving along the maturation curve and should help reduce carbon emissions over the years to come [*10*]. Another challenge is the integration of electrification into existing chemical manufacturing processes, which may require significant infrastructure and capital investments. One firm reduced its CO_2 output by

FIGURE 1. Electrification using renewable energy sources has obvious environmental benefits, but there are also opportunities for improvements in process reliability and reduced energy-cost uncertainty

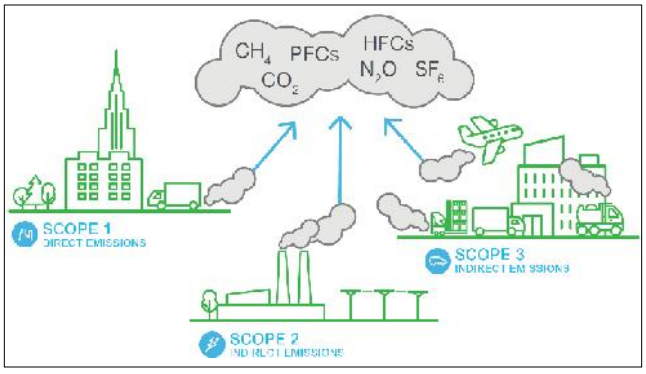

FIGURE 2. Manufacturing sites must consider the three scopes of emissions as described by the Greenhouse Gas Protocol

electrifying turbines, but it only lowered its electricity consumption after optimizing its overarching energy architecture. Procurement and integration of electricity-powered technologies, as well as architecture redesign, can come with hefty upfront price tags, even if longterm costs eventually fall below a manufacturer's fossil-fuel-powered baseline.

Finally, the regulatory landscape is one without official standards or frameworks for the electrification in chemical manufacturing. Unclear guidelines for how to proceed with new process changes can leave manufacturers concerned about the safety implications of new technology implementation in a holding pattern.

A mindset shift

Industrial organizations also tend to lack agility, a key ingredient for successful business transformations — in this case, catalyzed by electrification. Making strides in electrification will require a mindset shift as much as it will require procuring and integrating new assets and technologies.

Chemical manufacturers must do away with the all-or-nothing mentality and become comfortable with incremental changes. To enjoy the nimbleness of other industries, chemical manufacturers must first gain better visibility into their operations.

For example, today's digital technologies allow manufacturers to match energy consumption to actual demand and look at grid performance and forecast consumption targets. This visibility can enable a more transitional approach. Rather than trying to make a binary swap away from fossil fuel to electrification, manufacturers can instead incrementally electrify areas that are "low-hanging fruit" or will provide the biggest impact for their investment. From there, they can measure success and repeat it with a new process or application.

Incrementally using the combination of digital technologies, such as monitoring sensors and software, and electricity, can also help to reduce business risks. Electrified processes can mitigate uncertainty related to the availability and cost of fossil fuels, in part through onsite microgrids that improve energy efficiency.

Chipping away at low-hanging fruit

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with electrification and digital technologies can also help manufacturers to gradually infuse their operations with more durable industrial equipment, resulting in lower maintenance costs and even opening the possibility of remote monitoring. Taking a slow and steady approach offers manufacturers a valuable multi-pronged tool against electrification challenges, many of which stem from upfront costs or lack of an available solution.

The electrification of chemical processing facilities has the potential to significantly reduce environmental impacts and improve the sustainability of the industry. However, plant owners must overcome the inertia that is an obstacle to modernize operations. To break out of a state of rest, firms can employ "Electricity 4.0" — the confluence of digital tools and electrification — to drive efficiency and sustainability. This approach to energy management, coupled with a mindset shift toward incrementalism, can set the stage for improvements for years to come. ■

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Authors

Poonam Narang is the director of product management for Motor Management Solutions for Schneider Electric, North America (poonam.narang@se.com). She is passionate about solving customer problems through digital and sustainable solutions while moving her customers forward in their Industry 4.0 journey. Narang has over 15 years of combined experience in sales, strategy, business development and product management and has been with Schneider Electric for 4.5 years. Poonam holds a M.B.A. from Wake Forest University and a Bachelors in Engineering from Mumbai University.

Shailesh Chetty is a technical leader at Schneider Electric, located in Singapore (shailesh.chetty@se.com). He has over 14 years of industry experience and has been with Schneider Electric since 2018. Prior to joining Schneider Electric, he held roles at consulting firms where he engineered large projects in the oil-and-gas sector, as well as power-plant projects in a number of industrial sectors. Chetty's primary focus is to lead innovation in the new energy landscape for critical process industries, with special interest in process electrification, green hydrogen and energy efficiency. He holds an M.S. in power systems and electrical drives from Thapar University and a System Engineering L1 certification from Cesames in France.

Bulk Solids Centers Support Research and Education

Bulk-solids handling is a critical aspect of many product manufacturing processes throughout the CPI, but the field is often underappreciated. Research centers that specialize in bulk-solids handling and particle technology are important resources for expanding knowledge and solving technical challenges

Scott Jenkins
Chemical Engineering

Processes involving solid materials are very common throughout the chemical process industries (CPI), with many estimates suggesting that at least 70% of industrial processes involve the handling, conveying or processing of bulk solids materials. However, despite the prevalence of solids-handling processes and their importance to the production of many end products, solids-handling science and practice often remains underappreciated and poorly understood. In part, the gaps in understanding are a function of the complexity of bulk-solids-handling operations, and also because bulk-solids education is generally only cursorily included in most undergraduate mechanical and chemical engineering degree programs.

Specialized research centers focused on the study of bulk solids in industrial processes bridge some of the gaps in understanding by providing both education on bulk-solids-handling processes and equipment for students and working engineers, and conducting industry-relevant research on the behavior of powders and other solid materials at industrial sites (see sidebox, p. 41).

Complex, multidisciplinary field

The lack of expertise in solids processing results from several factors: some having to do with the nature of the field, and others having to do with logistical challenges in education. "Solids handling is a complex and multidisciplinary area that requires expertise from mechanics, materials science and chemical engineering," says Raju Dandu, director of the Bulk Solids Innovation Center (BSIC) at Kansas State University at Salina (bulk-solids.k-state.edu). "Further, there is a lack of clearly defined common core knowledge for undergraduate and graduate education between and across the complex bulk solids discipline," he explains.

The field of solids handling includes a wide range of diverse substances, complicating efforts to generate models that work well across multiple situations. Mike Bradley, director of the Wolfson Centre for Bulk Solids Handling Technology at the University of Greenwich (U.K.; bulk-solids.com), explains: "Every powder is different — even powders with the same name, and made to the same specification, will often display very different handling and flow properties if they are made in different plants. So you can't just draw conclusions from experience or available data."

"You need to get samples of the powder and characterize them in relevant ways — not just the particles sizes, densities, moisture contents and so on, but their bulk behavioral properties, such as flow properties measured in a shear tester, or pneumatic conveying properties measured in a pipeline test rig and so on. Without undertaking those steps... design is no better than guesswork," Bradley says.

Paul Mort, director of the Center for Particulate Products and Processes (CP3) at Purdue University (West Lafayette, Ind.; www.purdue.edu), echoes the challenges of solids flow properties. "Particle morphology is a critical parameter, and it affects how the substance flows in processes. Often particle shapes are complex and varied, and information on shape is not often included in specifications for materials," he says.

FIGURE 1. Solids handling involves multiple disciplines, including mechanical engineering, materials science, chemical engineering and others

The field of solids handling is full of "exceptions," notes Todd Smith, business and strategy manager at BSIC. Because many solid materials defy modeling, and often, the equations used to determine design parameters don't predict real-world behavior, it's very difficult to write educational textbooks and resources for those who are studying this area, Smith says.

But even if such resources were available, institutions of higher learning face challenges in offering additional courses in bulk-solids handling. The existing chemical and mechanical engineering undergraduate program curricula in the U.S. are already full at 120–128 credit hours, leaving little time for specialized solids courses. BSIC's Dandu says incorporating a wide range of multidisciplinary knowledge, as well as information on evolving technologies, into the curriculum can be difficult, because doing so requires close coordination among several different university departments and faculty. Additional hurdles include establishing access to experienced faculty and to a range of teaching resources, software and equipment.

RESEARCH CENTERS FOCUSED ON BULK-SOLIDS PROCESSES

The following research centers focus on processes involving bulk solids and powders.

Kansas State University Bulk Solids Innovation Center (BSIC; Salina, Kan.; bulk-solids.k-state.edu). BSIC has six laboratories for conducing industry-sponsored research, and a full-scale bulk-solids test bay. BSIC provides material properties testing, short courses, product and equipment testing, research, and consulting services.

Wolfson Centre for Bulk Solids Research and Technology at the University of Greenwich (U.K.; gre.ac.uk/engsci/research/groups/wolfsoncentre). The center offers consultancy, research and short courses for industries that handle powder or granular materials.

Centre for Bulk Solids and Particle Technology at the University of Newcastle (Callaghan, N.S.W., Australia; newcastle.edu.au/research/centre/cbspt/). The center works in conjunction with ***TUNRA Bulk Solids*** (TBS; bulksolids.com.au), an organization that provides high-level professional consulting and contract research service to the resources, process and manufacturing industries.

The Center for Particulate Products and Processes (CP3; engineering.purdue.edu/CP3) at Purdue University (West Lafayette, Ind.; www.purdue.edu). This integrated laboratory is shared among several different departments with connections to solids materials handling. CP3 has a pilot-scale facility for the study of powders.

Institute of Solids Process Engineering and Particle Technology at the University of Technology Hamburg (Germany; tuhh.de). Led by professor Stefan Heinrich, this center focuses on the industrial applications of fluidized-bed technology.

Particle Technology Research Center at Western University (London, Ont., Canada; powders.ca). The center is dedicated to research, development and innovation in particle technology.

Center of Excellence in Particle and Material Processing Technology (PMPT) at Chulalongkorn University (Bangkok, Thailand; research.chula.acc.th). This center focuses on nano-functional particulate materials synthesis and application, and bio-functional particulate materials synthesis and application.

Particle Engineering Research Center (PERC) at the University of Florida (Gainesville, Fla.; perc.ufl.edu). The center's vision is to innovate and transform particle science and technology advances into useful applications.

Centre for Industrial Bulk Solids Handling at Glasgow Caledonian University (Glasgow, Scotland, U.K.; gcu.ac.uk). This center is directed by professor Don McGlinchey, who provides consulting services.

Engineering Research Center for Structured Organic Particulate Systems (C-SOPS) at Rutgers University (New Brunswick, N.J.; c-sops.org). The center brings together a cross-disciplinary team of researchers to work with industry leaders and regulatory authorities to improve the way pharmaceuticals, foods and agriculture products are manufactured. C-SOPS partners include the New Jersey Institute of Technology, Purdue University, the University of Puerto Rico at Mayaguez, and more than 40 industrial consortium member companies.

Student interest

Before graduates are produced, however, students must be attracted to the bulk-solids field as an area of study. Achieving this has proven to be difficult as well. "Despite the industrial world's significant dependence on bulk solids handling operations, this discipline remains relatively unknown, when compared to related fields like mechanical and chemical engineering," says Dandu.

In part because of this lack of awareness generally, generating significant student interest in bulk-solids handling can be an uphill battle. "Most students will not take an interest in the final year option to study bulk-materials handling," says the Wolfson Centre's Bradley. "Despite the ubiquity and importance of bulk-solids handling across all process engineering disciplines — and the great career opportunities available — very, very few students take the unit in bulk solids handling," he explains.

The result is a shortage of engineering graduates with an emphasis in bulk-solids handling. "Considering that bulk solids make up more than 80% of items transported around the world, it is crucial to address the need for comprehensive education in bulk-solids handling as an option in both chemical and mechanical engineering," BSIC's Dandu says. "Offering a certificate program in bulk-solids handling can be an effective solution to meet this need."

Wolfson Centre's Bradley remarks, "I'd like to see powders and particulates included as part of the entire educational curriculum — liquids, gases and solids are studied at all levels of schooling and in college-level courses. Powders are just as important, not just to industry but in the natural environment as well."

However, there are forces working to overcome these challenges, including partnerships between academic centers and industry that are often observed in bulk-solids research centers. "Industry partners

can provide funding, expertise, opportunities for practice-based teaching, and real-world challenges to academic researchers," Dandu explains. "As a result, educational programs are incorporating and sustaining interdisciplinary research and training, leading to inter- and intra-departmental activities, such as developing interdisciplinary courses, creating interdisciplinary degree programs and introducing interdisciplinary faculty appointments." Graduates of such programs are "better equipped with a broader understanding of bulk-solids systems and the ability to work effectively across different fields to meet industry workforce needs," he adds.

Addressing industrial issues

Because only a relatively few engineering graduates have a specialized knowledge of solids, and because large companies have, for the most part, phased out in-house R&D laboratories with a focus on powders and solids, academic research centers in bulk solids have taken on a critical role in supporting both education and collaborative research.

"A significant part of BSIC's role is to provide continuing education focused on solids-handling processes," comments Smith. And for research, no other public entities are studying solids handling, "so there's no overall 'go-to' place for technology improvement," he says. Much of the research funding at BSIC and other centers comes from companies that are experiencing manufacturing challenges and looking to solve a problem in solids handling or processing.

Of Wolfson Centre, Bradley says most of its consultancy services to industry, whether for new plant design or troubleshooting, use techniques and knowledge generated in Wolfson's own research projects. In addition, the center runs short courses and conferences to present findings and educate interested parties.

"And quite a few of our Ph.D. students are sponsored by companies who use or make powders, or powder-handling equipment, and that can be a great way to generate not just new knowledge, but also an expert for their team." Bradley says.

"Applications knowledge for solids handling is the bottleneck," says BSIC's Smith. A lot of the knowledge is gained case by case, he adds, and BSIC is trying to share information with processing companies.

Examples of how research centers have helped solids-industrial clients are as varied as the solids themselves. BSIC's Smith talks about how BSIC often helps with process scaleup. In one example, a company changed product recipes, and the alteration worked well at laboratory scale, but caused problems at full scale. BSIC staff worked to figure out what was needed to make the large-scale process work with the new recipe.

Other examples of industrially relevant research conducted at BSIC include an analysis of fluidization of powder to improve a bagging operation, research to identify strategies for reducing product degradation during conveying operations; projects to improve understanding of abrasion resistance; dust safety and others, Smith says.

At Wolfson, Bradley says research projects related to handling food products and ingredients are a constant source of work at the center, and pharmaceutical materials are also common. Troubleshooting and re-engineering of plants that handle biomass and waste materials as feedstocks has been one of the main growth areas at Wolfson in recent years. "These are very challenging materials to handle and a lot of projects have huge failures that result from failing to do enough work to make sure the handling equipment is properly suited to the feedstock they will handle," Bradley says.

One recent research project at Wolfson involved developing a "Virtual Formulation Laboratory," aimed at companies designing powder formulations, often in food and pharma, but in other areas as well. "This has produced a software tool that formulators can use to predict how a potential new formulation will behave in manufacturing, based on information about the ingredients. Then they can see if it's likely to be problematic, and try out adjustments to the formulation to make it easier to manufacture, all from the desk," Bradley explains.

Additive manufacturing (AM; 3D

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FIGURE 2. Academic research centers focused on solids provide opportunities for companies to solve real-world industrial problems

printing) is also a fast-growing area that requires a great deal of solids-handling know-how, since the starting materials are often in powder form. Bradley and Perdue's Paul Mort both mention AM as an active area of research, often for automotive and aerospace applications. "Powder quality is really critical to finished part quality — a rogue particle can cause a flaw in a part that will scrap it — so we're doing a lot of research in that area," Bradley says.

Pneumatic conveying

Pneumatic conveying is a prominent topic at bulk-solid research centers, both in research and for education (for a brief overview of pneumatic conveying, see the article on pp. 44–45). "In pneumatic conveying, a lot of the work comes in simply blowing the powder, measuring the relationship between air flow, solids flow and pressure drop in the pipeline, then using this information to design a new system," Bradley says. "But a surprisingly common issue we study is how materials of the same specification but made in different plants or bought from different suppliers, compare in handling."

In short courses, the two most popular subject areas have always been pneumatic conveying, and discharge from hoppers and silos, Bradley says. Companies come to us to get a better understanding of how to buy, manage and use these technologies, he notes, but safety issues — especially electrostatics, explosions, silo failure and so on also attract a lot of attention.

At BSIC, Smith says pneumatic conveying is also its most popular continuing education short course. "There are lots of variations in how to do it, and it's relatively easy to grasp the basic concepts of the process, but it's hard to understand how to troubleshoot, and often difficult to work out why certain materials behave in particular ways," he says.

Reaching into the future

BSIC director Raju Dandu says the megatrends of digital transformation and sustainability are set to significantly impact bulk-solids research and education, and the educational and industry communities must embrace and incorporate these technologies. "Digital technologies, such as design and analysis, simulation software, artificial intelligence, machine learning, virtual reality, augmented reality and data analytics, are enabling researchers to gain a better understanding of the behavior of bulk-solids storage, conveying, and handling, leading to the design of more efficient systems." Additionally, Dandu says, "these technologies are being integrated into educational programs, providing students with hands-on experience using state-of-the-art tools for bulk-solids research and systems design, as they address problem-, project- and outcome-based learning."

The focus of the CPI on sustainability is "driving the development of new processes and technologies for handling bulk solids that are more energy-efficient, produce less waste, consume less water, and have a lower environmental impact," Dandu comments. "Educational programs are also incorporating sustainability principles, product- and systems-lifecycle management and circular-economy concepts into their curricula, providing students with the knowledge and skills needed to design and operate sustainable bulk-solids systems."

Both digital transformation and sustainability "encourage a multidisciplinary approach to bulk-solids research and education, bringing together experts from different fields," Dandu says, and are also "driving greater collaboration between academia and industry in the field of bulk solids." ■

Scott Jenkins

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Pneumatic Conveying Basics

Pneumatic conveying is a versatile method for transporting powders and other solid materials within chemical process plants. Success depends on understanding science and applying specific experience

Doan Pendleton
Vac-U-Max

IN BRIEF

NEGATIVE VERSUS POSITIVE PRESSURE
SYSTEM SELECTION AND DESIGN
PRODUCT CHANGES

Undergraduate engineering programs include little instruction about powder handling. While there may be some cursory education about the mechanics of pneumatic technologies and the chemistry of powders, engineers entering industrial processing and manufacturing industries rarely have a knowledge base sufficient to tackle a powder-handling project without the guidance of an experienced engineer or the expertise of a trusted supplier (see part 1, pp. 40–43).

The science of pneumatic conveying involves formulas to determine parameters like airflow and vacuum pressure. However, after all the science and spreadsheets, the success in designing a system that delivers peak performance while preserving product quality lies in the ability to understand powder characteristics and how those characteristics interact with equipment design. This type of "tribal knowledge" is not formulaic and draws upon decades of experience with tens of thousands of different materials and their behaviors to complement scientific principles.

Negative versus positive pressure

Pneumatic conveying uses air to either push (positive pressure) or pull (negative pressure) solid material through a conveying line. Negative-pressure systems suck the material through the lines, while positive-pressure systems blow, or push, material down the line. Factors other than material characteristics, such as conveying distance and the need for higher conveying rates, dictate the choice between negative- and positive-pressure systems.

Negative-pressure pneumatic-conveying systems (which constitute the majority of pneumatic conveying applications) include a pickup point where material enters into the conveying system, conveying tubing where material is transferred between equipment; a vacuum receiver (filter receiver), which serves as an intermediate holding vessel for materials; a vacuum source that powers the system; and a control panel.

Pneumatic conveying systems are also categorized by dilute-phase conveying, where the air-to-product ratio is higher, and dense-phase conveying, which injects less air and more product into the conveying line (Figure 1). Most systems use dilute-phase conveying, but dense-phase systems are used as applications dictate. There are some instances where semi-dense or semi-dilute systems are appropriate. Dilute-phase systems employ higher velocity rates than dense phase systems.

System selection and design

Pneumatic-conveyor manufacturers do not expect users to determine themselves which type of system is needed. Expert conveyor manufacturers determine, by compiling a great deal of information about the application, which type of system will best meet all

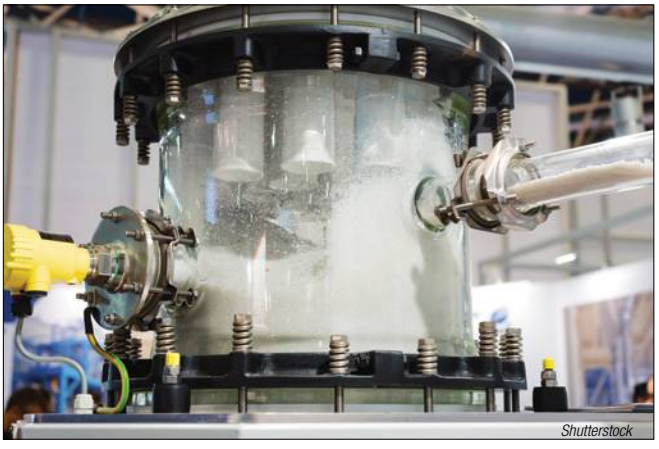

FIGURE 1. Pneumatic-conveying systems have varying air-to-product ratios

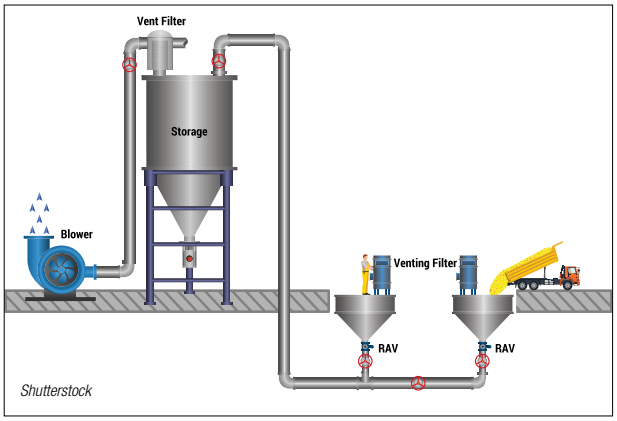

FIGURE 2. The introduction of material into a conveying system, and the discharge of that material, can cause processing problems

the desired outcomes of the user. Whether employing vacuum technology for increased throughput, dust containment, labor savings, cleanliness, addressing complex convey routes, or safety and environmental reasons, the success in adding pneumatic technology lies in the ability to understand powder characteristics and how those characteristics interact with equipment design. While some conditions favor a specific pneumatic technology (such as conveying heavy materials at longer distances), in large part, material characteristics are the primary factor in determining system design across all types of pneumatic conveying systems.

The bulk density of a material is one of the first indicators of design in terms of sizing various system components, such as vacuum receivers and air sources. Bulk density leans toward the science end of design and helps determine how many cubic feet per minute (CFM) of air is necessary to move the material through the convey line. Generally speaking, materials with bulk densities between below 55 lb/ft^3, but above 25 lb/ft^3 are fairly easy to convey, while heavier materials require more power and larger vacuum receivers. Fine powders with low bulk density, such as fumed silica, present their own set of challenges and may require more filtration and therefore larger vacuum receivers than medium density powders.

Once solid material is in the conveying line, it often conveys without issue, even if the material is not free-flowing. However, introducing material into the conveying line or discharging material from the system can be problematic, and cannot be overlooked.

An understanding of how a particular substance will behave under certain conditions is essential when designing a vacuum transfer system. The behavior of a particular material – whether it is free-flowing, sluggish or non-free-flowing — is important data to relay to a conveyor manufacturer.

Non-free flowing materials require the most modifications at the pickup point. The pick-up point is the most customized component in a pneumatic conveying system because it is crucial for feeding material into the conveying system. Getting the air-to-solids ratio correct during the feeding process in order for material to feed into the line at proper velocity is crucial. Even free-flowing materials, like peanuts or gel caps, sometimes need extra consideration or require equipment modifications.

Cohesive and lightweight powders are prone to sticking and can cause bridging at the pickup point. Steady product flow into the material line and a proper solids-to-air ratio are critical with sticky materials. If the solids-to-air ratio is too high, the line will plug, and if it is too low, the system is just pulling air and not transporting enough material. Feed devices assist getting material into the line at a constant rate.

With challenging powders, specially designed agitative-feed devices regulate flow. These devices include one or several types of flow-promotion devices such as vibrators or impactors, aeration pads, headload deflectors or polished surfaces, but rotary or screw feeders are sometimes used when necessary.

With ultra-fine powders, such as carbon black, filters can clog and choke the entire conveying process. At the top of the material receiver housing, filters separate the product from the clean air traveling back to the vacuum producer. The filter media, the number of filters, placement and cleaning cycle is extremely important for challenging materials.

Product changes

While powders can affect equipment performance, equipment can also affect the product. When moving powders and dry materials, changes in particle size, density and texture can occur and potentially affect product performance. This is one of the most common challenges faced by packagers and why it is of utmost importance to use the specific materials of interest to test the performance of system's design before it is sold. For example, peanuts impacting fixed metallic elbow sweeps (90-deg turns) in the conveying line can turn into peanut butter. To combat this, flexible hose is used to prevent material from impacting the same location repeatedly.

When pneumatically transferring gel caps, the capsules can hit the side of the hopper, creating additional noise in a facility. To combat this, vacuum conveyor manufacturers can add tangential inlets and internal soft baffles to eliminate noise and protect delicate solid products from damage.

Working with a seasoned expert in pneumatic transfer of powders and bulk solids costs more on the front end, but working out any issues that may arise before a system is installed on the production floor can save money in the long term. ■

Edited by Scott Jenkins

Author

Doan Pendleton is president of Vac-U-Max (69 William Street, Belleville, NJ 07901; Phone: 973-759-4600; Email contact: noraashmen@vac-u-max.net). Pendleton's professional experience includes over 30 years in the design, engineering, manufacturing and marketing of dry bulk-material transfer systems and industrial vacuum-cleaning systems. His application expertise extends across several industry sectors, including food, pharmaceuticals, plastics, chemicals and non-woven materials industries. Pendleton holds a B.S. degree in marketing and management from Suffolk University.

Interphex 2023

Interphex 2023 — a leading global event for the pharmaceutical industry — takes place at the Javits Center in New York City April 25–27. Over 400 exhibitors will be on hand presenting product innovations and services. A technical conference also takes place, with topics ranging from inspection, formulation, cell and gene advancements, pharma 4.0, automation and more. A small selection of products being exhibited at Interphex is presented below.

Lugaia USA

This liner system protects employees and products

Traditional equipment used to fight contamination, such as dust masks and extractors, are no longer sufficient to protect employees or products, due to the expanding field of disease control involving highly active ingredients and substances. These higher concentrations of dust and powder become increasingly toxic, requiring cutting-edge containment technology. This company offers concept-to-finish containment systems, including flexible packaging and transfer solutions. The company's continuous liner system (CLS; photo) is used to ensure the safety of personnel and products by forming the interface between the production outlet and the continuous liner package. The liners are made of user-specific foil material, and are available in various sizes and folding heights. The liners are manufactured in the company's class ISO 5, ISO 7 and ISO 8 cleanrooms, and welded according to established industry processes on qualified systems. Axial folding enables film lengths of up to 265 ft (80 m). Fold height and foil length are dependent upon film thickness. Special CLS liner sizes for customized foils can also be produced. Stand 1441 — *Lugaia USA, LLC, Ponte Vedra, Fla.*
www.lugaia.com

Coperion K-Tron

Sanitary pneumatic receivers for pharmaceutical applications

The P-Series pneumatic receivers (photo) are suitable for applications with a higher degree of sanitary requirements, such as vacuum conveying of difficult flowing powders and active pharmaceutical ingredients (APIs). These receivers are designed to provide solutions for difficult conveying applications for the pharmaceutical industry and engineered to be easy to lean and disassemble with wash-in-place (WIP) and containment options available. The sanitary receivers can be used for gain-in-weight or loss-in-weight feeder refill applications, simple up and in systems, such as indirect or direct blender loading or conveying blends to tablet presses or capsule fillers. They typically convey materials including free flowing to poorly flowing powders, flakes and granular materials requiring gentle conveying. They are available in three models: the P10 (10-L capacity) can convey up to 600 kg/h; the P30 (30-L capacity) can convey up to 1,800 kg/h; and the P100 (100-L capacity) can convey up to 4,000 kg/h. Stand 2258 — *Coperion K-Tron, Inc., Salina, Kan.*
www.coperion.com

Optima Packaging Group

Multiuse, cell and gene therapies and freeze-drying technology

A number of technologies are being exhibited by this company, including flexible, low- to high-speed filling systems, new solutions for cell and gene therapies and the latest trends of freeze-drying technologies. This company offers a total turnkey approach to handle complex projects for filling lines with isolator and freeze-dryer combined. The MultiUse platform enables flexible production systems for every application and batch size. The technology is focused on processing vials, syringes and cartridges all in one machine platform. A high degree of automation, robotic technology and a state-of-the-art component-handling system enables agile pharmaceutical manufacturing and provides ultimate flexibility to all market and production demands. The portfolio ranges from small scale, like MultiUse Lab for research and development, up to high-speed solutions for commercial manufacturing up to 24,000 units per hour. The company also provides freeze-drying equipment. The new LYO-Scale freeze-drying system (photo) is tailored for the production of small- to medium-size quantities. The freeze-dryer design fits into existing buildings and can be configured for an optimal

production layout. — Stand 1519 — *Optima packaging group GmbH, Schwäbisch Hall, Germany*
www.optima-packaging.com

Major expansion of facility for manufacturing drug substances

Last December, this company officially opened (photo) its £6-million project expansion project in Alnwick, U.K. The new facility provides a state-of-the-art drug-substance manufacturing capability that can deliver integrated support for drug-candidate selection through to early clinical development and beyond. The expansion delivers multipurpose capacity of up to 15 GMP reactor streams with reactor volumes ranging from 5 to 150 L, and tactical deployment of batch or continuous-flow chemistry technologies to optimize drug substance manufacturing processes. The facility has been designed adopting Industry 4.0 principles, with the inclusion of a predictive process control system (PharmaMV), improving the transfer from small-scale process research and development (PR&D) into manufacture of multi-kilogram quantities of drug substance for clinical use. — Stand 1260 — *Quotient Sciences, Nottingham, U.K.*
www.quotientsciences.com

A one-stop shop for product inspection systems

This company supplies a number of product-inspection systems, offering Safeline metal detectors and x-ray inspection systems, Hi-Speed inline checkweighers, CI-Vision vision systems and PCE Track & Trace, serialization and aggregation solutions. For example, the company will demonstrate its newest x-ray inspection system, the X34C, which has an optimized focal distance to enhance detection of dense physical contaminants of individually wrapped pharmaceutical products at high line speeds. Its compact design, only 700 mm in length, can be installed into the smallest of spaces to avoid line constraints when space is at a premium. The company also offers systems to mark packs with individual serial numbers for full traceability of the production or packaging process and to collect critical corresponding process data. All packaging formats — from single cartons and bundles to shipping cases and ready-to-ship pallets — can be marked and verified. The company also offers connectivity and data-management solutions and global service support. Stand 2361 — *Mettler Toledo Product Inspection, Lutz, Fla.*
www.mt.com/pi

Combining multiple operations into a single machine

The TwinPro technology (photo) combines two separate batch oral-solid dosage (OSD) processes — high-shear granulation and fluidized-bed drying — into a single process unit running on a single machine. This combination leads to reduced process space, less capital equipment investment, an overall reduction in process time and total elimination of open product transfer. These advantages make it suitable for containment applications. Also being exhibited is the MultiLab, the newest laboratory-scale innovation that incorporates multiple OSD processes into a single R&D unit. This is a modular concept, which includes the primary main module with a variety of optional process modules, including fluidized bed, high-shear granulation, milling, tablet coating and blending technologies. The MultiLab is available for both aqueous and solvent process applications, and solutions are available for containment applications and WIP. Stand 1329A — *Glatt Air Techniques Inc., Ramsey, N.J.*
www.glatt.com

Consistently homogenize and emulsify product with this unit

The Quadro Ytron Z Emulsifier (photo) is said to deliver unparalleled consistency and control of high-shear process applications, such as immiscible-phase emulsifying and homogenizing, wet grinding, deagglomeration and fine solids dispersing. Incorporating up to three sets of toothed rotor/stator heads, the Z Emulsifier processes product while passing multiple shear zones in a single-pass. The result is consistent, repeatable quality at capacities exceeding conventional multi-pass technology. Stand 2437 — *IDEX MPT, Inc., Waterloo, Ont., Canada*
www.idex-mpt.com ■

Gerald Ondrey

Quotient Sciences

Glatt Air Techniques

IDEX MPT

INTERNATIONAL
POWDER & BULK SOLIDS
CONFERENCE & EXHIBITION

Anton Paar USA

Rembe GmbH Safety+Control

Schenck Process

The International Powder and Bulk Solids (iPBS; www.powderandbulkshow.com) Conference and Exhibition, which includes a conference program of topics related to solids handling, as well as a tradeshow highlighting all types of solids-handling process equipment, will be held April 25–27 at the Donald Stephens Convention Center in Rosemont, Ill. The following is a small selection of products and equipment that will be displayed on the tradeshow floor at iPBS 2023.

Surface area and pore analyzer enables speed and precision

This company's new Nova series (photo) for measuring surface area and pore characteristics has been designed to deliver speed and precision without tradeoffs. Consisting of four models, the Nova series delivers high analysis throughput by combining four sample-preparation stations with up to four analysis stations in a single compact footprint. Patented features like Nova analysis mode combined with a suite of intelligent dosing algorithms significantly reduce measurement times. Five-point Brunauer-Emmett-Teller (BET) analyses of up to four samples can be performed in as little as 20 min. High throughput is combined with high precision and sensitivity. Exclusive features, like TruZone active coolant-level control, enhance analysis sensitivity by actively maintaining the cryogen level to ensure a small cold zone around the sample cell. A dedicated P_0 cell and transducer constantly monitor the saturation pressure over the course of a measurement to provide highly accurate relative pressure readings, yielding precise and reproducible isotherms. Reproducibility above 2% can now be obtained even with an absolute surface area as low as 2 m^2 in the sample cell. Stand 2830 — *Anton Paar USA Inc., Ashland, Va.*
www.anton-parr.com

Measure CO and humidity with continuous self-calibration

Excessive caking can result in spontaneous combustion in commercial spray-drying applications. To avoid caking, humidity and carbon monoxide are used as indicators to ensure a safe process, but combined measurement systems cannot clearly distinguish between these two indicators. The CO.Pilot Synergistic CO and Humidity Measurement system (photo) autonomously performs continuous comparisons of measured gas data with a synchronized database of stored reference gases that serve as "fingerprints" of the selected process and combustion gases. This allows the possibility to perform a realtime check to continuously verify the measurement accuracy as a self-calibration. At the same time, the realtime fingerprint analysis eliminates cross-sensitivity to other gases in the measurement spectrum, which is problematic with other commercial gas analyzers. A proprietary evaluation algorithm enables the measured supply and exhaust gas stream values to be compared in real time. Thus, if an increased CO concentration is detected due to spontaneous combustion during the process, countermeasures can be initiated immediately. Stand 1238 — *Rembe GmbH Safety+Control, Brilon, Germany*
www.rembe.us

Use this feeder in high-sanitary process applications

The MechaTron 3-A feeder (photo) was designed specifically for use in food and dairy process applications where equipment must meet 3-A sanitary levels or equivalent. All welds, radii, seals, surface finishes and gaskets, as well as contact and non-contact materials meet 3-A standards. Available product features include a.c. and d.c. drive packages, an FDA/USDA-accepted Coni-Flex flexible conical feed-hopper, helix configurations for feedrates from 0.30 to 330 ft^3/h (8.5 to 9,300 L/h) and an unmatched ability to disassemble, clean, reconfigure and service from the non-process side of the feeder. A domed hopper cover and open bottom frame speeds and optimizes draining during and after wash-down cycles. Smooth, crevice-free product contact surfaces help prevent the formation of bacteria. Stand 1737 — *Schenck Process LLC, Kansas City, Mo.*
www.schenckprocess.com

Robust and versatile radar level measurement at a lower cost

UWT Level Controls

NivoRadar NR 4000 and NR 7000 radar sensors (photo) are used for continuous level measurement in solids and liquids. Level measurement with radar is based on electromagnetic waves. A radar sensor sends a bundled electromagnetic wave, which is reflected by objects as an echo and evaluated by the sensor. In addition to the NivoGuide NG 3000 and NG 8000 series of guided-wave radar sensors, the NivoRadar NR 3000 portfolio of non-contact radar devices has been expanded. The extension of the non-contact radar series for continuous level measurement is equipped with 80-GHz frequency-modulated continuous-wave (FMCW) technology and a very narrow beam angle. Stand 1344 — *UWT Level Controls LLC, Memphis, Tenn.*
www.uwtgroup.com

This diverter valve is ideal for frequent product changes

Coperion K-Tron

This company's WYK-CIP diverter valve (photo) is suitable for residue-free cleaning in manufacturing processes with frequent product changes, where the highest requirements in hygiene and purity apply. The WYK-CIP is designed for inline material handling of hygienic and difficult-to-handle powders. This valve can be used in pneumatic conveying systems to divert transfer of the powder to different locations, and it is often used in return lines in spray drying applications. Stand 2015 — *Coperion K-Tron, Salina, Kan.*
www.coperion.com

Industrial vacuum pumps with resiliency to volatile materials

Italvacuum

The Saurus 939 high-vacuum piston pump (photo) is designed to intake volatile substances in many applications, including vacuum drying, reactions, distillation, crystallization, filtration, evaporation and polymerization processes. The pump's cylinder, piston, segments and head of the machine are made of special acid-resistant cast iron. The other parts are made of cast iron, specialty steels and filled polytetrafluoroethylene (PTFE). All vacuum pumps of the Saurus 939 range have two completely independent lubrication circuits — a circuit for the process part, with calibrated injection of fresh oil, thanks to the LubriZero system; and a circuit for the mechanical part, with recirculated oil to minimize waste. Stand 2706 — *Italvacuum, Borgaro, Italy*
www.italvacuum.com

Scott Jenkins and Mary Page Bailey

For details visit adlinks.chemengonline.com/84646-20

What Manufacturing Sites Can Learn from Municipalities About Water Loss

Accurate water-monitoring technologies support short- and long-term sustainability goals in both municipalities and the industrial sector

James Dunning
Syrinix, a Badger Meter Brand

In recent years, São Paulo, Cape Town and other major world cities have come dangerously close to running out of water, and the criticality of water as a key business asset has never been clearer. Indeed, managing water risk is now identified as a chief priority by industrial giants around the world. But, what about the industrial sector's municipal bedfellows on which they often rely for supply? Beyond the industrial sector's monitoring and strategizing headlines, the day-to-day business of identifying leaks and bursts and reducing their occurrence in the first place is an emerging area for minimizing water loss and meeting environmental, social and governance (ESG) goals. For leak and burst management and reduction, copying some pages from the municipal playbook could well pay dividends for the manufacturing sector (Figure 1). This article provides some success stories in leak and burst monitoring from municipal water organizations, and discusses the key takeaways for industrial water users.

Water loss in a municipal system

Aging infrastructure and shrinking freshwater sources are challenging water utilities and pushing them to take every available step to protect treated water from loss. Providing clean water for a price that consumers can absorb is in the crosshairs of strategy for water utilities, even while daily residential demand has been increasing due to a dramatic rise in people working from home. Additionally, utilities are facing growing pressure from regulators to step up water conservation and environmental protection measures. In response to those pressures, municipalities have been focusing on the following key areas, which are also applicable to the management of any industrial water process:

- Leak detection — both to save water and because a significant proportion of bursts on larger pipes start as small leaks
- Instantaneous burst locating so that the damage caused by bursts, which can be significant, is minimized
- Identifying and removing the pressure spikes that occur on the network from operations and usage. Such spikes can significantly accelerate the failure of a pipeline

FIGURE 1. Burst and leak monitoring systems can help water utilities and industrial users make great strides in their water-conservation efforts

Detect surges and avoid bursts

At the heart of leak detection and response strategies are pressure- and acoustic-monitoring technologies. Small monitoring units may, for example, contain a precise pressure sensor, with network timestamping, and a hydrophone for leak detection. Such a system can fit easily into hydrants and chambers and collect data that can be analyzed to detect leaks and pressure spikes (also called "transients") and also to locate a burst. Monitoring units may also include a corresponding software to generate alerts and alarms to inform operators of critical events, such as when pressure valves are above or below desired limits. Modern, cloud-based data platforms can automatically track the source location of bursts and major pressure events.

High-resolution monitoring allows users to detect and identify the source of pressure spikes that can, over time, cause significant wear and tear on pipes and other assets. Pressure spikes can be caused by irregular pumping and valve operations and also major offtakes being turned on and off quickly without any dampening. If a burst does occur, the monitoring technology should also be configured to locate the burst quickly (within seconds), allowing immediate mitigating actions to be implemented to minimize water loss, damage and system downtime.

Alongside those measures, acoustic leak-detection technology allows users either to survey or permanently monitor pipelines. With the units acting in pairs, the vibro-acoustic signature of leaks can be detected — ideally, with external noises filtered out. From there, the

FIGURE 2. Municipal water providers certainly serve many different end users than the industrial sector, but the key lessons related to conserving water and minimizing system bursts and leaks are crucial for all water suppliers and users

exact location of a leak can be identified, allowing for monitoring and repair before the leak deteriorates into a burst.

Industrial water use and loss

It is estimated that industrial water use represents about 5% of total direct water withdrawals (surface and groundwater sources) in the U.S. (around 18.2 billion gal) and 12% of the public water supply. Among the most water-intensive industries are agriculture, biotechnology and pharmaceuticals, metals and mining and forest products.

Leaks can represent a significant economic factor for an industrial facility. For plants relying on public water supply, the cost of water includes not only the price of incoming water and the sewage fee for discharge, but also the cost incurred through any treatment or processing (typically for chemicals and energy) that a plant carries out for its own purposes, plus associated labor and other costs. The full cost of water can end up being three to four times the cost charged by the utility.

Moreover, industries operating in water-stressed areas of the world — the southwestern U.S., for example — likely will be facing a changing regulatory landscape with regard to acceptable water use and loss, making leak detection and elimination a critical element in any industrial water strategy.

Companies can begin the process of determining water loss and potential leaks with a water-balance calculation, or a comparison of input versus output, considering such factors as evaporative loss, input to product streams and wastewater discharge requirements. When output is shown to be less than input, a leak may be the culprit. Effective pressure and acoustic monitoring can help industrial facilities to avoid the loss of a tremendous amount of water and associated expense.

Use case: EVWD

East Valley Water District (EVWD; www.eastvalley.org) provides water and wastewater services to 103,000 residents of San Bernardino County, Calif. (Figure 2). EVWD staff felt that evaluating the existence and severity of pressure transients was a prudent step in actively managing its water-distribution system. The main goal was to reduce line breaks caused by pressure transients, aging assets, bedding failures and corrosion. With the cost of repairing a single break ranging from $10,000 to $25,000, reducing these events can generate significant savings. EVWD decided to deploy a network-calming project using smart pressure monitors.

To identify critical areas, the team imported EVWD's historical data on breaks and combined this with geographic information system (GIS) data using open-source GIS software to create a map of "hot spots" of concern associated with specific pressure zones. Possible transient sources — such as pumps, valves and user points — were then identified near each hot spot. Using this water-main-break heat map, pressure monitors were deployed at pumping stations and on hydrants across the network to confirm transient propagation across the monitoring area.

To cover the entire service area, the monitoring project was undertaken in phases, focusing on the most critical areas on the heat map first. To identify transients of concern, two types of data were analyzed, as described below.

Summary pressure data. This is a summary of the minimum, mean and maximum pressure values registered over a period of 1 or 15 min based on constant readings at 128 samples per second, also known as high-sample-rate data.

Pressure sensitivity data. A pressure sensitivity threshold, known as an S3 score, was set in each pressure monitor to alert when transient events occur. S3 scores are a non-dimensional measure of pressure-transient activity calculated within the unit itself. Large and sudden changes result in a high score; small changes over a longer period result in a lower score. Tracking and profiling pressure sensitivity data is a good measure of the pipeline's transient activity, indicating if the activity level has increased or if mitigation work has been successful in reducing it.

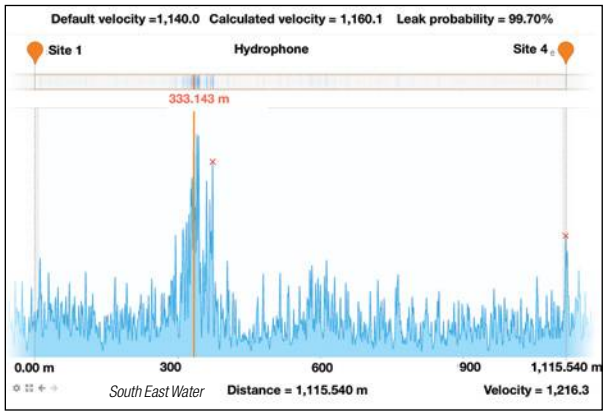

FIGURE 3. Pressure monitoring data were used to pinpoint the location of a simulated leak

FIGURE 4. The pressure drop related to the simulated leak is seen in the analysis graph. The map shows the location of the leak

A summary of pertinent data can be sent multiple times per day and high-sample-rate data are typically only sent when the pressure sensitivity threshold in each unit is breached.

At EVWD, the collected pressure data were then analyzed to identify the root source of the transients via triangulation. First, similar transient wave shapes from all monitored sites were grouped to identify clusters of recurrent transient events produced by different sources. The analysis then focused on identifying the source of these events. Locations of automatic triangulation results were plotted on the water-main-break heat map and matched with the transient clusters previously identified, pinpointing the source of the recurrent transient event.

During the first phase of monitoring, the analysis found that the aggressive starts and stops of a specific pump station created transient events that added additional stress to the pipe. The insights revealed by the analysis enabled EVWD to identify the specific assets that produced these transients and take action to mitigate the transients to calm the flow.

One benefit of high-resolution monitoring is that it identifies smaller, more frequent transient "noise" that can, over time, cause significant wear and tear on the pipes and other assets. These can often be remedied more quickly and less expensively than larger transient situations, improving the overall network health.

Based on this project, EVWD has now initiated a process of relocating the monitors to different locations on a rotating basis to provide ongoing analysis of hot spots throughout its service area. They continue to monitor trouble spots, line-break events and user pressure concerns to assess the results of the calming.

With thousands of assets spread over a wide geographic area, EVWD gained access to actionable data to guide their troubleshooting and network-optimization efforts.

Use case: South East Water

For South East Water (www.southeastwater.co.uk), the utility serving the U.K.'s South East region, residential use spiked in 2020, with per-person water use increasing by a staggering 16% due to the rush of people newly working from home. That increased the utility's focus on minimizing leaks and main breaks.

Recognizing that pressure transients are a major source of damage to pipes and other network assets, leading to leaks and breaks, South East Water initiated a pilot program to assess how leak detection and intelligent pressure monitoring could help it identify and reduce the causes of leakage. They chose a compact system that combined standard pressure monitoring with acoustic monitoring to support both leak detection and network calming. Detailed monitoring data could be sent in real time to a cloud-based platform for analysis.

The pilot monitored a stretch of water main running alongside a busy road. Three monitoring sites covered a total distance of 1,376 m. At each location, a pressure monitor was installed in an existing fire hydrant. Built-in network time protocol (NTP) clock synchronization facilitated accurate global positioning system (GPS) locations without requiring site modifications. The three units were installed as a string to confirm the distance over which the leak noise could be observed and to assess the performance of using GPS time-synchronized correlations with NTP.

The team conducted a daytime test, opening a hydrant to simulate a leak when busy road traffic was observed. The pressure monitors generated the hydrophone data (Figure 3) that enabled them to locate the simulated leak to within 1 m. In opening the hydrant, they triggered a pressure event on the valve opening analogous to a burst, which was also captured by the monitors — a valuable finding to support network-calming efforts.

Figure 4 indicates the pressure drop at the moment the leak was started. Real-time datasets from the three pressure monitors were analyzed by software to triangulate the location of the leak. With an integrated GPS receiver recording the unit's position, an algorithm was applied to the data, the exact location was pinpointed, and the user immediately alerted. The triangulated result, as shown by the red flag in the map in Figure 4, indicated the location of the simulated leak to within 1 m. Since the outcome of the trial was positive, helping South East Water extend its record of hitting its yearly leakage targets, the group now plans to do a larger-scale project.

Applying learnings

As water-system operation and water preservation falls under greater scrutiny, for companies' own internal ESG goals and for external environmental regulation, taking care to identify leaks and bursts early, and also reducing the activities exacerbating them, is a logical and cost-effective step. As the cost of water increases, eliminating leaks represents a growing economic opportunity as well. Technology used effectively for large, pressurized water-distribution systems in municipalities works just as well for water systems in manufacturing applications, and with the same benefits. ■

Edited by Mary Page Bailey

Author

James Dunning is the general manager of Syrinix (Email: james.dunning@syrinix.com). With more than 25 years of experience in the utility sector, Dunning joined Syrinix as CEO in 2010, leading its growth as an award-winning global market leader in providing high-resolution data-led insights for water utility networks. Prior to Syrinix, he served as a lawyer and is a graduate of the London Business School, as well as holding senior positions within the corporate utility sphere and as an entrepreneur in the renewable energy sector.

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Rota-Cone® Blender

The **Paul O. Abbe** Rota-Cone® blender is the ideal choice for thorough and gentle blending of powders or crystalline products. Because this tumble blender has no shaft seals or agitator, cleaning is simplified and cross-contamination minimized. All internal surfaces the Rota-Cone® can be inspected from the single loading hatch. Liquids can be added through the optional spray line and a pin agitator can be added to facilitate liquid dispersion, granulation or de-agglomeration. Loading can accomplish with our automated drum loading and discharging system. Controls including variable frequency drive and PLC can be supplied in NEMA-4X or NEMA-7&9 explosion-proof design. Available sizes range from 0.1 to 500 cubic feet working capacity.

www.pauloabbe.com

Handle virtually any bulk solid material

Flexicon stand-alone equipment and automated plant-wide systems convey, discharge, condition, fill, dump and weigh batch bulk materials dust-free

Flexicon engineers and manufactures a broad range of equipment that handles virtually any bulk material, from large pellets to sub-micron powders, including free-flowing and non-free-flowing products that pack, cake, plug, smear, fluidize, or separate.

Individual bulk handling equipment includes: flexible screw conveyors, tubular cable conveyors, pneumatic conveying systems, bulk bag dischargers, bulk bag conditioners, bulk bag fillers, bag dump stations, drum/box/container dumpers, and weigh batching/blending systems. Each of these product groups encompasses a broad range of models that can be custom engineered for specialized applications, and integrated with new or existing upstream and downstream processes and storage vessels.

All equipment is available to food, dairy, pharmaceutical and industrial standards.

For large-scale bulk handling projects, Flexicon's separate Project Engineering Division provides dedicated Project Managers and engineering teams on four continents to handle projects from concept to completion. Working with each customer's preferred engineering firm or directly with their in-house team, Flexicon adheres strictly to the customer's unique standards, documentation requirements and timelines through a single point of contact, eliminating the risk of coordinating multiple suppliers.

Flexicon's worldwide testing facilities simulate full-size customer equipment and systems, verify performance prior to fabrication, demonstrate newly constructed equipment for visiting customers, and study the performance of new designs.

Flexicon offers stand-alone bulk handling equipment as well as plant-wide systems integrated with new or existing processes

The company recently doubled the size of its manufacturing facility and world headquarters in Bethlehem, PA, and also operates manufacturing facilities in Kent, United Kingdom; QLD, Australia; and Port Elizabeth, South Africa.

www.flexicon.com

Unique Vibra Screw system provides consistent flow of material from bins to belts

A challenge many engineers face when designing and specifying a bulk solids handling system is ensuring an even, continuous flow of materials from a storage bin or silo onto a conveyor or weigh belt feeder. Many materials tend to bridge, rat hole, or clog before being discharged from storage, which can result in an uneven, interrupted flow, negatively impacting operational quality and production schedules.

Fortunately, **Vibra Screw** has engineered a unique solution for difficult materials handling challenges. Storage bins in systems handling stubborn materials can be equipped with a Vibra Screw bin activator and a vibrating discharge nozzle to provide an even flow with plus/minus 1-2 percent accuracy onto a weigh belt feeder or conveyor.

The original patented dished head bin activator by Vibra Screw has proven to be efficient, convenient, and economical for moving dry bulk materials out of storage on demand. When mounted on the conical section of a new or existing static bin, it helps meet the challenge of assuring continuous flow and preventing additional material load onto a belt feeder from the head load. This is particularly important during initial start-ups.

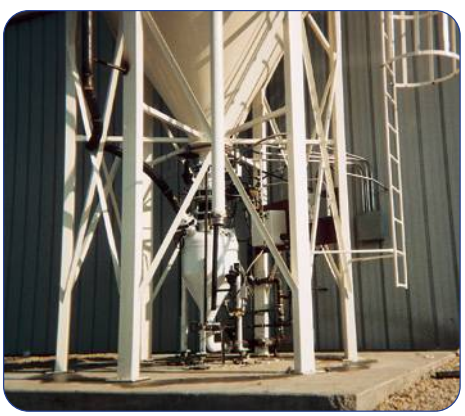
Vibration is applied to the flexibly mounted bin bottom by a Vibra Screw gyrator. A baffle located in the bin activator relieves head load pressure and imparts vibratory forces into the material. Isolators confine vibration to the bin activator and eliminate vibration transmission to the bin itself.

When a Vibra Screw vibrating discharge nozzle is used in conjunction with the bin activator, a reliable method for feeding materials onto the belt is provided. The vibrating nozzle further prevents material from hanging up in the bin or flooding uncontrollably as it is discharged and turns 90 degrees across a conveyor or belt surface.

The consistency of the material flowing downstream can be further enhanced when a Vibra Screw weigh belt feeder is incorporated into systems. These feeders are designed to convey a wide range of materials, including powder, grains, flakes, and pellets. They can be used as an integrator to monitor material weight and rate flow, or as a weigh feeder to precisely control material flow by weight into process. The unique weigh system reduces dead load and applies live load directly to two platform load cells, which are externally mounted for easy access and maintenance.

www.vibrascrew.com

HDP 4000 Full-Line Concept System



Dynamic Air dense phase pneumatic conveying systems have been proven in over 15,000 installations worldwide. They handle a wide range of materials and bulk densities at rates from a few hundred pounds to 400 tons per hour, over distances exceeding 5,000 feet. The HDP 4000 Full-Line Concept dense phase pneumatic conveying system has many advantages over more traditional dense phase concepts with regard to degradation and energy consumption. The system utilizes the DC-5 Air Saver technology to achieve an optimum pressure balance while counteracting forces of friction. The Full-Line Concept system conveys materials at low velocity and high density while utilizing very low air consumption. The enclosed system is clean and can be fully automated to convey to packaging or process bins. Very few moving parts are utilized, as the prime mover is standard plant compressed air at 100 PSIG. Dynamic Air Full Line Concept systems have proven to be very low in maintenance and are very flexible with regard to space and various custom plant situations.

www.dynamicair.com

Dynamic Air HDP 4000 Full Line Concept dense phase pneumatic conveying system

Innovative redesign: BEUMER Group introduces a modular system for its palletizers

Rethinking the Machine

The BEUMER paletpac series is keyed to the characteristics of the packaged goods and complies with the customers' requirements for packing patterns and pallet dimensions.

The **BEUMER Group** has completely redesigned and overhauled its paletpac range of robust palletizers. The modular machines now have identical or similar components and modules and – wherever possible – are based on the same design. The total number of components has been reduced and faster deliveries are possible. If replacement parts are later needed, this will also go faster. BEUMER configures the modules according to each customer's requirements, tests them in-house and installs them on the customer's premises, saving time and money.

The new model range not only makes configuration easier, but it also simplifies installation. Previously, it was necessary to use forklifts with a capacity of up to eight tons. Now a capacity of five tons is sufficient. The modules are designed so that they can be picked up from two different sides. This simplifies assembly in confined spaces.

BEUMER has redesigned all the modules in its paletpac series in terms of function and utility. It has optimized the motors and drives in the belts and streamlined the design at transfer points, making transport processes much gentler. The size of the assemblies has also been modified for greater efficiency, boosting the performance of certain modules.

The new BEUMER paletpac has been equipped with a larger deposit table. With maximum layer dimensions of 1,500 x 1,300 millimeters, it can accept bags filled with bulk materials on euro pallets or pallets with other formats.

The developers have also redesigned the pusher, which is used in all BEUMER paletpac models. The undercarriage is the same for both single and double pushers, enabling users to increase the performance of the system later without making big adjustments to the modules.

When they modernized the paletpac, BEUMER's developers also improved its footprint. The control cabinet bays have a standard configuration, but a space-saving offset arrangement is also possible if required by the customer. The enclosure for the lifting gear also saves space. The Human Machine Interface (HMI) is located on the maintenance platform at the layer preparation level. If the operator needs to adjust, he or she can see the whole machine at once. Additional control units, for example in the lifting gear, can optionally be installed for even greater convenience.

www.beumer.com

Simple and efficient solidification of base ingredients for the cosmetic industry

The global cosmetic and personal care industry – estimated to be worth in excess of $500 billion a year – is built on beauty. From nail varnish to night creams, this is a market that sells glossy hair, glowing skin and glamorous good looks.

The ingredients used to create these products however, are more mundane. Sun tan lotions contain compounds derived from fatty acids. Lanolin, a natural wax obtained from sheep's wool, is used in eye liner and lipstick. Bees wax is found in hand lotions, hair products and lip balm. Other commonly used materials include fatty alcohols, waxes, organic compounds, pigments, resins and surfactants.

All the examples above share one thing in common: the base ingredients are processed on **IPCO** solidification systems. Easy transport, storage, handling and dosability of these ingredients is key and this is achieved by converting them into consistently sized, free-flowing beads using IPCO's Rotoform technology.

Rotoform models are available to solidify low and high viscous melts (up to 40 000 mPas) at temperatures up to 300 °C. The range includes systems for batch processing of between 10-20 kg/hr (the cosmetics industry often uses materials in small quantities) and models capable of handling 100-500 kg/hr.

The process is simple but extremely efficient. The product is delivered to the system in melt form. The Rotoform itself consists of a heated cylindrical stator and a perforated rotating shell that turns concentrically around the stator. Precisely metered drops of the product are deposited across the whole operating width of a continuously running stainless steel cooling belt.

The speed of the Rotoform is synchronized with the belt to allow a gentle deposition of the liquid droplets onto the moving belt without deformation. Heat released during cooling and solidification is transferred via the steel belt to cooling water sprayed underneath.

The Rotoform process converts the melt into solid beads of a defined and consistent size, a form that is free flowing and ideal for handling, storage, dosing and blending.

The Rotoform process is inherently clean and hygienic. Easy access to all key areas simplifies cleaning and most major components are stainless steel by default. IPCO's experience of developing Rotoform systems for specific applications has enabled the development of solutions in full compliance with GMP guidelines.

https://ipco.com/products/rotoform-granulation-systems

Lechler: Spray expertise built over a century of delivering cutting-edge nozzle designs.

For over 142 years, **Lechler** has taken pride in designing spray nozzles used in critical areas of many industry segments such as Steel, Cement, Power, Pulp & Paper, Oil & Gas, Chemical, Automotive, Electronics, Food and Beverage, Pharmaceuticals, Agriculture, and more. We have built unparalleled knowledge in delivering engineered spray solutions to meet and exceed our customers' process goals. With a portfolio of more than 45,000 nozzles, Lechler is able to offer our customers the most comprehensive product range. From consulting for developing a customer's crucial process application to building CFD models based on actual droplet sizes, Lechler's focus on precision and accuracy distinguishes itself from competitors. In addition, Lechler is the only spray nozzle manufacturer that provides chevron-type mist eliminators. Today, Lechler offers an array of standard and custom nozzles that produce the smallest droplet sizes, create the narrowest droplet size distribution, has the largest free passages and capacities, generates the most spray impact, and delivers

the biggest droplet sizes to minimize droplet entrainment.

Lechler has more than ten full cone nozzle designs that excel in one of the above attributes. Such a level of design variety enables Lechler to select the most optimum design and nozzle size to achieve the best performance. Poorly selected nozzles can lead to millions of dollars in unrealized potential and cause thousands in damage from unplanned outages and downstream equipment for companies. For example, a more efficient dual fluid nozzle requires very short residence time leading to a smaller vessel volume resulting in lower fabrication and structural costs.

Each year, Lechler invests a significant portion of revenue in R&D and new product development to stay at the forefront of nozzle technology and deliver cutting-edge performance to its customer. Lechler is proud to have built the most modern and technologically advanced spray testing lab at our headquarters in Metzingen, Germany. This lab is our bedrock for innovation. Our customer also benefits from our lab as they can easily order tests on any nozzle of their choosing to measure precise droplet size, pressure vs volumetric flow, spray distribution, and spray impact.

Today, Lechler is focusing on developing products and services for Oil and Gas and Specialty Chemical industries in the areas of enhancing mass transfer in open spray towers, improving absorption and quench units, high performance tank cleaning spray nozzles, and injectors to delivery liquid in process streams.

www.lechlerusa.com

Inline high shear mixers that induct powders, homogenize and pump

Ross SLIM Technology employs high shear for rapid and complete mixing of powders into liquids, avoiding agglomerates and dust formation

The **Ross** Solids/Liquid Injection Manifold (SLIM) is a technology for dispersing challenging powders such as thickeners, pigments and other additives using a specially modified high shear rotor/stator generator.

In an inline configuration, the SLIM mixer pumps liquid from the recirculation tank while simultaneously drawing powders from a hopper. As the liquid stream enters the rotor/stator assembly, it immediately encounters the powder injection at the high shear zone. The mixture is then expelled through the stator at high velocity and recirculated back into the tank. In a few short turnovers, solids are completely dissolved or reduced to the desired particle size (deagglomerated).

This method for high-speed powder injection is ideal for dispersing small concentrations of hard-to-wet solids like CMC or xanthan gum (⇢5%). It is equally effective for solid loadings as high as 70%, as in the case of some titanium dioxide or magnesium hydroxide slurries. By introducing solids sub-surface where they are instantly subjected to vigorous agitation, issues like floating powders, excessive dusting, and formation of stubborn agglomerates "fisheyes" are eliminated. Because the SLIM generates its own vacuum for powder induction and does not rely on external eductors or pumps, it is free of clogging and simple to operate.

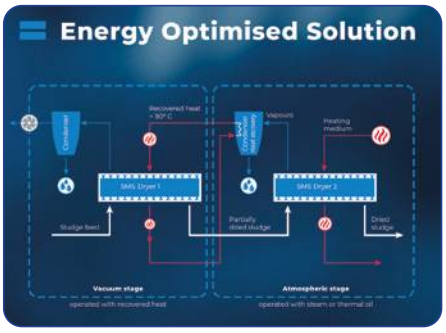
Options include automated skid packages where the SLIM mixer is piped to a jacketed tank and supplied with flow meters, load cells, solenoid valves, level sensors and thermocouples all integrated into a PLC recipe control panel. The SLIM technology is available in batch (in-tank) design as well.

Pictured are two 25 HP ROSS SLIM Model HSM-405SC-25 with a NEMA 4 Class II, Div. 2, Group G purged control system programmed to operate both the mixer and the pneumatically-actuated 1.5" powder feed valve, managing the flow of the dry phase (powder feed hopper not shown).

Established in 1842, Ross is one of the world's oldest and largest manufacturers of process equipment, specializing in mixing, blending, drying, and dispersion.

www.mixers.com

45% saving in heating energy with new drying process



Drying means evaporation of liquids, often water from sludges or similar products. This process duty requires much input of energy.

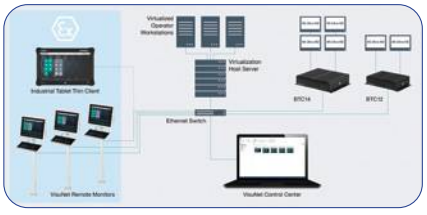
Unfortunately, traditional drying processes do not satisfy today´s requirements of energy use and efficiency. They use the heating energy only once although more efficient process principles are well known. In evaporation technology it is common practice to apply multiple effect evaporation. The process is split into sequential steps. In each step vapours are generated and condensed. The energy which is set free during condensation is recovered and is re-used to heat a previous step.

This process scheme is introduced to drying technology by **Buss-SMS-Canzler**. A 2-stage drying process is provided. Stage 2 is operated at atmospheric conditions - as in traditional drying. Stage 1 is operated under vacuum conditions, which results in a lower evaporation temperature than in stage 2. At such low evaporation temperature, the temperature level of the condensation of stage 2 is sufficient to heat stage 1. In this way, the condensation energy from stage 2 can be used a second time.

As a result, approximately 45% of heating energy can be saved in the drying process.

Like the multiple-effect evaporation, the evaporation and the drying under vacuum is also well known to Buss-SMS-Canzler. The operating principle of applying the product in a thin film on the heating wall allows the thin film dryer to perform very well under vacuum. An example of this application is the drying of sewage sludge. **www.sms-vt.com**

Modular Design for Maximum Flexibility



The modular platforms of the HMI portfolio from Pepperl+Fuchs offer individual solutions for applications ranging from non-hazardous areas to Zone 1.

The VisuNet GXP and VisuNet FLX HMI device families enable maximum flexibility for use in the process industry. The modular design allows HMI systems to be configured to meet precise individual needs, providing extremely quick, simple service options in the field. This means that a comprehensive range of technologies, installation options, and peripherals is available for customers. Each HMI system consists of at least one computer unit and one display unit, each of which can be individually configured. The operator workstations from Pepperl+Fuchs are designed and certified for use in ATEX/IECEx Zone 1/21, Zone 2/22, and Div 1 applications. In addition, all products can be used in non-hazardous areas.

The VisuNet RM Shell 5 firmware developed by Pepperl+Fuchs for VisuNet thin clients is based on Windows 10 IOT 2019 LTSC and offers a simple way to make individual adjustments. The highest safety standards and flexible configuration options allow connection to numerous virtualized and conventional process control systems.

The product range is rounded off by rugged box thin clients for use in control rooms and switch cabinets. In addition, mobile tablet thin clients from **Pepperl+Fuchs** ensure a complete portfolio for virtualized and conventional process control systems. With the VisuNet Control Center software, the thin clients can be managed seamlessly and centrally — from Zone 1 to the control room. **www.pepperl-fuchs.com/hmi**

Contamination-free drying of HAPI products

Customized containment systems by PINK GmbH Thermosysteme

The drying of highly active and toxic substances in test centers, laboratories and production calls for protective measures for the operator as well as the product.

To ensure the best protection for both and for the safe handling of HAPIs, **PINK** has combined its vacuum drying oven type VSD with an isolator and mobile pressure nutsch. The developed system type VSDIN is ideal for drying these substances.

Due to its construction concept, the drying oven VSD offers an ideal basis for GMP-processes and for extremely pure and contamination-free terms for producing sensible and even high toxic products. The interior has rounded edges with no jointings and no hidden surfaces. All surfaces are visually controllable for the operator. The heated shelves as well as the top and the bottom are constructed double-walled and are connected to the side walls absolutely jointless.

The integrated isolator is equipped with ergonomic arranged gloves for safe handling of the product. The inside is also designed according to GMP. A CIP-device as well as spray guns grant a proper cleaning in order to avoid any cross contamination.

For applications in which the filling and filtration of the product takes place outside the isolator, PINK offers a mobile pressure nutsch for contamination-free docking. This enables the prefiltration of liquid products before the drying process proper, thus optimizing work processes.

The GMP-compliant system VSDIN features a main and lock chamber, RTPs for product infeed and discharge, an integrated vacuum drying oven VSD as well as a weighing system and sieve mills.

The operator and the product are protected at all times, no cross-contamination, no product loss.

www.pink.de/en

LiB production: mixers for laboratory and Gigafactory

Customized particle design as the key to success

In the production of li-ion batteries, **Eirich** intensive mixers are convincing all along the line: from the functionalization of active material particles to the production of coating compounds for separators as well as wet to dry electrode mixtures. The adaptation of operating parameters and mode of operation alone enables users to fulfill a wide variety of tasks with a single mixer type.

Particle coating, a central basic operation in LiB production

Coating of particle systems and suspending for the production of wet electrode mixtures are central basic operations of LiB production. Eirich intensive mixers in their design as Eirich MixSolver with a horizontally arranged mixing vessel are ideally suited for suspending, but as mixers with an inclined mixing vessel they are equally well suited for coating, but above all granulating particle systems.

Coating and thus functionalizing active material particles with different nanostructured particles such as aerosils or conductive carbon blacks is a common intermediate step in the production or use of active materials. If these processes are to be carried out completely dry, without the detour via suspensions and spraying processes, mixers are needed that generate high shear rates in the powder bulk. The microgranulation die patented by Eirich also shows excellent performance in this task. The optimized shear field at the outer edges of the die breaks up the agglomerated nanoparticles so well at the appropriately selected die speed that they can dock onto the surface of the active material particles and coat them in the best possible way within a very short time.

Macroscopically, this change at the particle surface is expressed by a noticeable change in the bulk density and tamped density, but also in the flow properties of the bulk. Depending on the selected mold speed and mixing time, particle systems can be designed in a simple way.

Perspectives for the LiB production of tomorrow

Eirich mixers for coating with aerosols have been in use in production for many years with throughputs of several tons per hour. Active materials coated with conductive carbon black form the basis for dry electrode manufacturing (DBE), which is currently under development and eliminates the energy-intensive coating and drying process. The first pilot and production plants based on this concept using Eirich mixers are already being planned.

In summary, Eirich technology offers a wide range of possibilities with regard to the production of all kind of energy storage devices.

Simple scale-up from laboratory to gigafactory, e.g. from the universal 1l laboratory mixer EL1 to the 900l intensive mixer RV16 or MixSolverÒ RV12 for large-scale production.

www.eirich.com

Jenike & Johanson is passionate about Bulk Solids Handling. Why? Because particles matter!

Particles – regardless of their size – play an important role in the efficiency and safety of plant operations. **Jenike & Johanson** is the world's leading technology company for bulk material handling, processing, and storage. Their skilled, highly technical team of experts and their industry-leading innovations have successfully delivered bulk material engineering solutions for over 55 years, increasing the safety and productivity of manufacturing plants across many industries.

Bulk materials and their flow properties are at the core of Jenike's work. Every one of their projects is truly unique, and their solutions are highly customized. Clients are offered maximum flexibility in selecting services required to meet their bulk material handling needs. The company does not follow the "one size fits all" concept, as this can be a dangerous pitfall in engineering. Decisions made during the feasibility and engineering stages of a project are critically important for its success. If bulk solids systems are not engineered from the outset to handle the unique characteristics of the materials in use, process start-up time can be significantly delayed, and design capacity may never be reached. Jenike & Johanson is the trusted advisor for solving and preventing those issues.

Their services include:

- Bulk Material Testing for All Types of Powders & Bulk Solids
- Conceptual & Functional Engineering of Bulk Handling Equipment
- Structural Engineering of Bulk Material Silos and Structures
- Custom Equipment Design and Supply

Jenike & Johanson has developed proven and practical ways to design powder and bulk solids storage, handling, and conveying equipment to promote reliable, uniform, and unrestricted bulk material flow. They have worked on more than 7,500 projects and tested over 15,000 unique powders and bulk solids. The unique combination of science, engineering, and design capabilities and an engineering team with nearly 1,000 combined years of hands-on experience is unmatched by any other bulk material handling organization.

www.jenike.com

Reduce labor costs and improve productivity with Hapman's new Automated Solutions

At **Hapman**, our Ideas that Move motto not only points to the fact that our products literally move materials, but also represents our continual pursuit to incorporate new ideas to solve customer challenges.

Safety and Efficiency have long been and will continue to be top of mind for our customers in mining, manufacturing, and processing materials related to food, chemicals, pharmaceuticals, plastics, and minerals. These industries are facing increased challenges related to available skilled labor that is not predicted to subside. We have also seen growing demand for solutions that provide maximum design resilience to allow seamless response to changes in customer demand and processing requirements.

Hapman has partnered with proven suppliers of robust industrial automation to develop new ways to safely and efficiently move dry bulk solids. Our goal is to enable truly automated processing and packaging from incoming raw material to outgoing finished product. The Autonomous Material Conveyors and Automated Bag Unloaders are the next step, allowing the removal of operators within the processing portion of the value stream, freeing those resources for maintenance and other higher value tasks.

Autonomous Material Conveyors, as with many AMRs, connect islands of work without the need for fixed infrastructure and manual intervention to trigger and execute transfer of materials between portions of an operation. Hapman AMCs can be seamlessly integrated into existing processing equipment truly functioning in place of a traditional conveyor in your operation.

Hapman's LaborSave Automated Bag Unloading can reliably accept a pallet of material and introduce it into a process in under 10 minutes with no operator involvement at 99.9% efficiency. This product is the perfect complement with Hapman Bulk Unloaders in Batching and Blending Systems. Hapman offers options integrated with all Hapman Conveyors, dramatically improving process uptime while resolving labor constraints.

Combining both these technologies can automate the supply of material from warehousing and removal of empty pallets eliminating employee intervention in the area beyond routine maintenance.

For more information, call 800-427-6260, e-mail sales@hapman.com, or visit **www.hapman.com**

Economic Indicators

2021 2022 2023

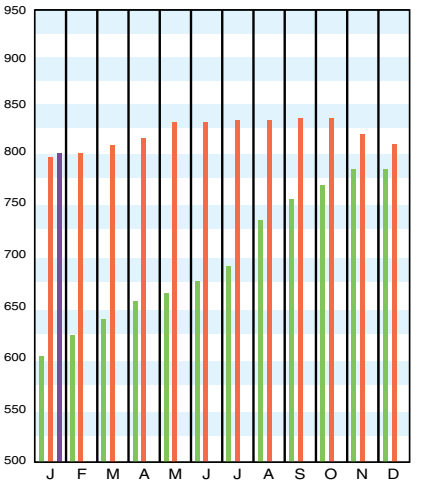
Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Jan. '23 Prelim.	Dec. '22 Final	Jan. '22 Final
CE Index	801.4	802.9	797.6
Equipment	1,015.6	1,016.1	1,009.2
Heat exchangers & tanks	832.7	840.8	860.3
Process machinery	1,030.4	1,031.4	993.1
Pipe, valves & fittings	1,426.8	1,427.2	1,457.0
Process instruments	561.4	558.5	568.9
Pumps & compressors	1,389.1	1,332.4	1,213.2
Electrical equipment	797.3	790.7	698.9
Structural supports & misc.	1,113.7	1122.5	1,115.5
Construction labor	357.7	359.0	345.6
Buildings	795.6	794.2	831.3
Engineering & supervision	301.2	311.8	310.7

Annual Index:
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.8
2022 = 816.0

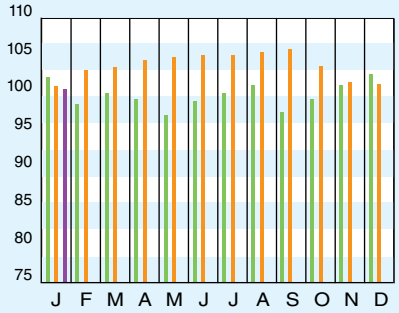
Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)



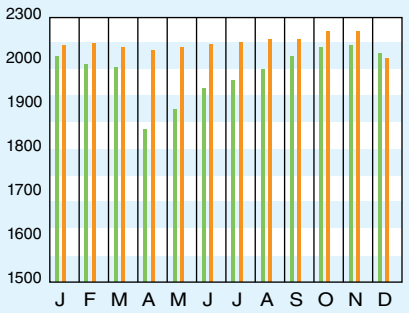
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS		YEAR AGO	
CPI output index (2017 = 100)	Jan. '23 =	98.8	Dec. '22 =	98.0	Jan. '22 =	99.2
CPI value of output, $ billions	Dec. '22 =	2,056.9	Nov. '22 =	2,121.1	Dec. '21 =	1,939.1
CPI operating rate, %	Jan. '23 =	79.4	Dec. '22 =	78.8	Jan. '22 =	80.7
Producer prices, industrial chemicals (1982 = 100)	Jan. '23 =	331.0	Dec. '22 =	336.1	Jan. '22 =	336.4
Industrial Production in Manufacturing (2017 =100)*	Jan. '23 =	100.2	Dec. '22 =	99.3	Jan. '22 =	100.0
Hourly earnings index, chemical & allied products (1992 = 100)	Dec. '22 =	209.5	Nov. '22 =	209.5	Dec. '21 =	196.8
Productivity index, chemicals & allied products (1992 = 100)	Jan. '23 =	91.1	Dec. '22 =	89.8	Jan. '22 =	96.8

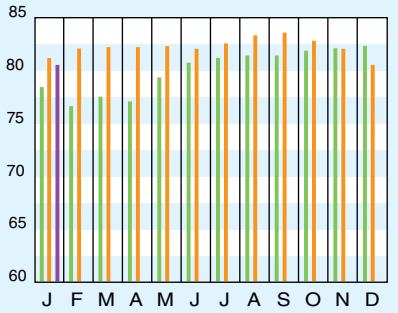
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for January 2023 (most recent available) declined from the previous month's value, continuing a series of seven consecutive monthly decreases in the CEPCI overall value. In addition, the final value for December 2022 was downwardly revised from its preliminary value in a larger-than-usual adjustment that may be due in part to recent volatility in steel prices. For January 2023, there were decreases observed in the Equipment, Construction Labor and Engineering & Supervision subindices, while the Buildings subindex was slightly higher. The current CEPCI value now sits at 1.0% higher than the corresponding value from January 2022.